INSTRUMENTAL NEUTRON ACTIVATION ANALYSIS (INAA) CHARACTERIZATION OF PRE-CONTACT BASALT QUARRIES ON THE AMERICAN SAMOAN ISLAND OF TUTUILA

A Thesis

by

PHILLIP RAY JOHNSON II

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF ARTS

December 2005

Major Subject: Anthropology

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Approved by:

Chair of Committee,	Frederic B. Pearl
Committee Members,	Suzanne L. Eckert
	William D. James
Head of Department,	David L. Carlson

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ABSTRACT

Instrumental Neutron Activation Analysis (INAA)
Characterization of Pre-contact Basalt Quarries on
the American Samoan Island of Tutuila. (December 2005)
Phillip Ray Johnson II, B.A., University of Kentucky
Chair of Advisory Committee: Dr. Frederic B. Pearl

This thesis presents a material-centered characterization of 120 geologic samples from four fine-grained basalt quarries on the Samoan Island of Tutuila. Previous unsuccessful attempts at definitive Tutuilan quarry differentiation have utilized x-ray fluorescence (XRF). In this study, clear differentiation of each analyzed quarry was achieved using instrumental neutron activation analysis (INAA). Biplots of canonical discriminant function scores for the INAA data illustrate clear separation based on the variation in chemical composition between each quarry. The samples analyzed not only define quarry separation, but also provide the "core group" for a preliminary baseline necessary for future artifact-centered provenance studies. Inclusion of these "core group" samples in the baseline was confirmed by stepwise discriminant analysis. These findings suggest the ability to determine quarry of origin on the island of Tutuila, which can elucidate the importance of individual Tutuilan quarries in the export and exchange of fine-grained basalts.

ACKNOWLEDGEMENTS

I would first like to thank the wonderful people of American Samoa whose friendship and hospitality have been the most rewarding aspect of the thesis process. So many people on Tutuila helped with this project along the way. To everyone who has touched this project from its inception to its completion, I would like to say *fa'afetai tele*. Thank you to the villages of Alega, Alofau, Leone, and Tula. Very special thanks are in order for Mr. David Herdrich, territorial archaeologist, deputy SHPO, and all around nice guy. Without his moral support, enthusiasm, and expertise this project could have never been successful.

I also owe an enormous amount of gratitude to Dr. John Enright and Ms. June Auelua of the American Samoa Historic Preservation Office, whose generous funding and logistical support made this project possible. For their wonderful hospitality, great thanks go to the ASPA archaeology team: David Addison, Tim Currey, Natasha Lynch, Jackie Maisano and Siaki Vaueli. Thanks guys for the nicest digs I've ever had on the island, Thanksgiving dinner *fa'a Samoa*, and the scariest movie of all time. Thank you to NPS archaeologist Ms. Epi Suafoa and her husband John for their assistance and, most importantly, their friendship. Great thanks go to Tisa and Candyman for the fantastic *umu* dinner and allowing me in their "backyard".

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encouragement from my cohort at Texas A&M. Special thanks to Ms. Kristine Nicole Ferre for the wonderful illustration of basalt tools on page 5.

Last and most certainly never least, I need to thank my parents and my girlfriend Holly for their love, patience and support. Throughout this entire process they have kept me confident, sane and happy. I love you all very much.

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CHAPTER I

INTRODUCTION

Project and Goals

This project attempts to distinguish between individual fine-grained basalt quarries on the Samoan island of Tutuila utilizing geochemical characterization. It is designed to differentiate Tutuilan basalt-quarries based on chemical composition. The key objective of this research is to establish the intraisland source variation of four Tutuilan basalt quarries, providing a preliminary baseline for future artifact-centered endeavors. Prior to definition of Tutuilan quarry variability, artifacts cannot be confidently sourced to their quarry of origin. This analysis of Tutuilan basalt samples definitively differentiated the four quarries included, creating a baseline or "core group" of samples for future artifact-centered provenance studies. The definitive characterization of these four quarries creates the foundation for confident provenance studies on the fine-grained basalt artifacts of Tutuila.

The archipelagos of Polynesia (Figure 1) stretch great distances across the Pacific. Some islands are isolated by hundreds of kilometers of open water, but Polynesian ocean voyaging tradition allowed for continued contact and societal interaction based on interisland trade networks (Davidson 1977; Kaeppler 1978).

This thesis follows the style of *American Antiquity*.

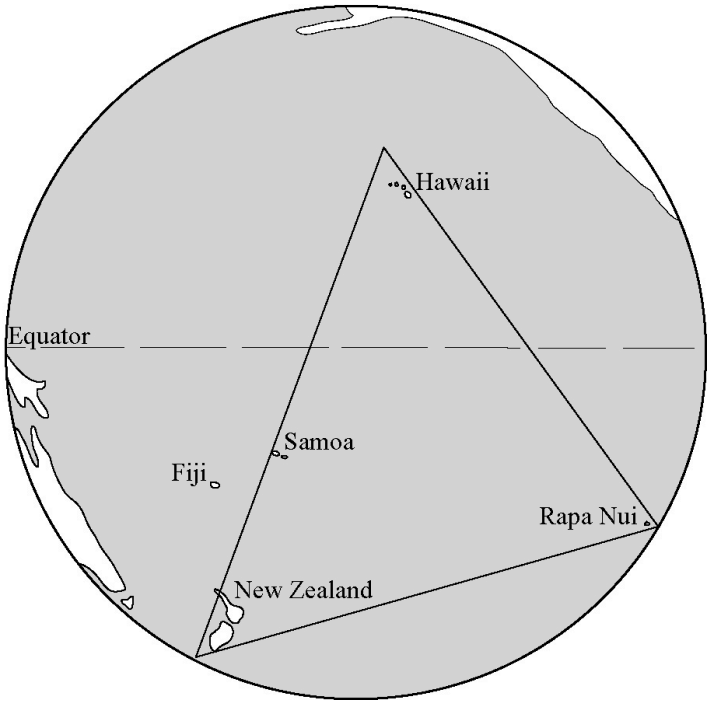

Figure 1. The Polynesian triangle.

Certain Polynesian societies may have heavily relied on this interaction to augment the marginal environments they inhabited and subsequently abandoned before European contact (Weisler 1997, 2002, 2003b). Considering the rapid displacement of lithic industries by European introduced metal implements and the subsequent loss of knowledge of stone tool trade, basalt provenance studies potentially offer the best evidence for continued Polynesian seafaring and the complex socioeconomic machinations of interisland contact and exchange.

There are three objectives inherent in the successful completion of this project. Initially, the analysis must determine whether geochemical variation in Tutuilan basalts

is detectable with INAA. Second, any detected variation must be sufficient to distinguish intra-island quarries. Third, and finally, if the first two objectives are met, I will have established a preliminary baseline data of Tutuilan quarry variation.

Successful completion of these objectives creates the foundation for Tutuilan artifact-centered provenance studies. Without properly established quarry variation, individual artifacts cannot be confidently assigned a source of origin. With the continued progress of chemical characterization in Polynesia (Weisler 2002, 2003a) and the complexity of questions centered on Samoan involvement in Polynesian basalt trade networks (Best et al. 1992), this level of analysis stands to be a valuable and necessary contribution to Polynesian archaeological research.

Church (1994) describes two major types of lithic provenance studies, artifact-centered and material-centered. Artifact-centered studies attempt to source artifacts to their source. Material-centered studies are focused on source material and are designed toward gathering baseline information, or estimating the mean and spatial distribution of the geological variability. Material-centered research is the initial comprehensive approach that allows further elaboration and progressive provenance analysis. A material-centered analysis is the proper initial method for determining source variation, and definitive characterization of source variation is a necessity for successful artifact-centered analysis. The research reported herein is material centered by design, and the necessary first step towards properly defining the variation of Tutuilan basalt quarries. This project is the next step necessary for comprehensive basalt artifact provenance studies in Samoa. I examine whether or not individual basalt quarries on the Samoan

Island of Tutuila can be identified and separated by discrete elemental signatures derived through geochemical characterization. The research was designed to address the problems associated with the characterization of multiple intraisland quarries.

Basalt Tools in Polynesian Prehistory

Lithic tools are the most robust and enduring cultural component of the Polynesian archaeological record. However the Pacific islands that comprise Polynesia lack a variety of high quality lithic sources for tool making. Although some obsidian, volcanic glass and other tool quality materials are intermittently available, fine-grained basalt is the best material found throughout the Polynesian expanse. Polynesians were left with no choice but to develop a flaked and ground stone tool technology utilizing this basalt. The basalt adze is the archetypal Polynesian artifact, and it has been recovered and described throughout the island Pacific (Figure 2). The adze may be the most celebrated artifact form in Polynesia, but bifacial and unifacial basalt flaked tools also pervade the prehistoric record.

Prior to the European introduction of metal in the late eighteenth century, the basalt tool was the pith of Polynesian technology. Such tools were an integral component of pre-contact society. They facilitated daily life. Tasks such as butchery, woodcarving, and even felling trees depended on various basalt tools. Although its physical form continues to litter Polynesian shores, the stone tool was so rapidly displaced by the introduction of metal implements that even the earliest European accounts and ethnographic sources are practically void of any notion of basalt industry. A mere two generations after European contact and subsequent introduction of metal, the

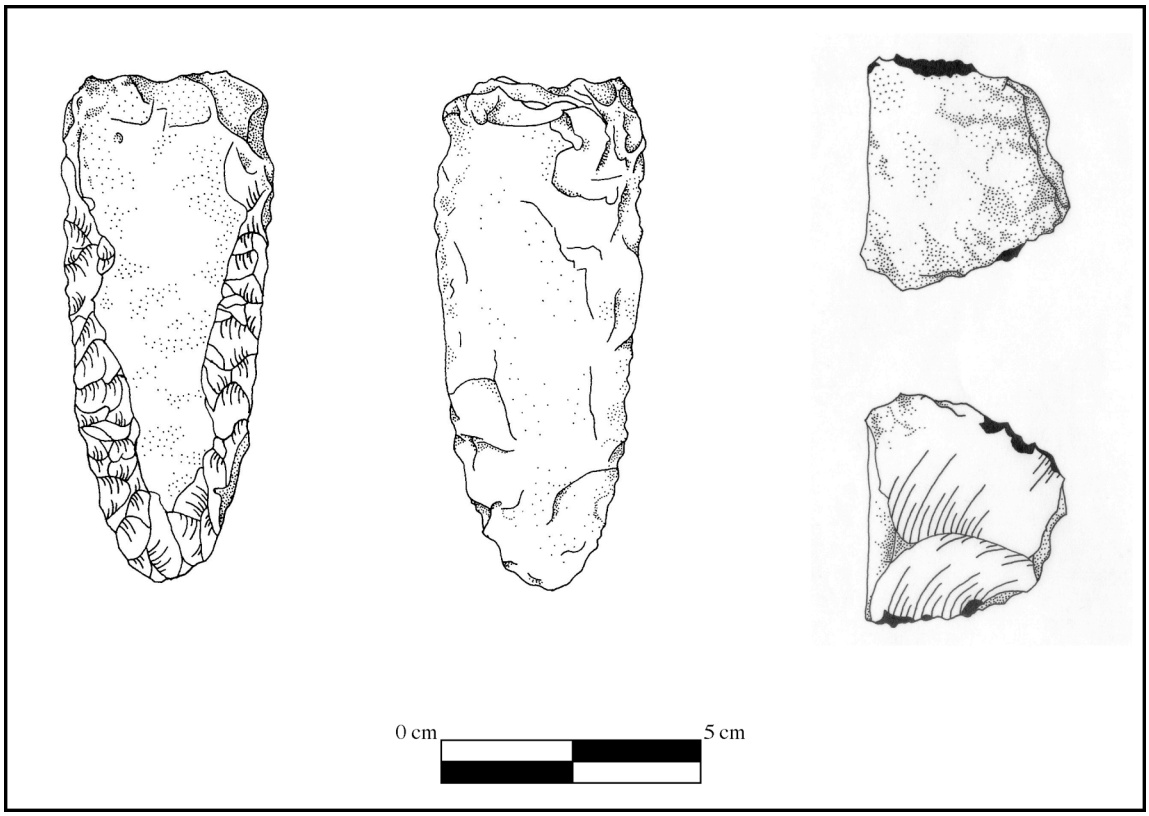

Figure 2. Basalt adze and flake from Tutuila, American Samoa.

missionary Heath (1840) refers to Samoan basalt sources and stone tool technology in the past tense. By the early nineteenth century the metal tool had completely erased the role of the basalt tool and its importance in trans-pacific socialization and trade. The metal implement not only supplanted lithic technology in Polynesia, it obliterated the tradition and knowledge of its industry in the matter of a few decades.

Virtually unaccounted for in the Polynesian ethnographic record, stone tools are ubiquitous in the archaeological record. However, not all islands containing basalt tools also contain access to tool quality basalt sources, suggesting transfer of basalt from

another island. This apparent transfer of material across the Pacific presents a distinct and meaningful opportunity for provenance study. Provenance studies, which trace the origin and dispersal of material culture, have aided archaeologists in the research of prehistoric economy and interaction. The most successfully and often utilized artifacts in provenance studies have been obsidian tools and ceramic vessels. However, considering the paucity of obsidian and the early prehistoric abandonment of pottery, basalt tools present the best vehicle for comprehensive provenance studies in Polynesia.

Types of Provenance Studies in Polynesia

Provenance studies in Polynesia have generally consisted of three categories of analysis: macroscopic observation, thin-section description and geochemistry (Weisler 1993b). Macroscopic observation of ceramic or lithic material culture is the most established order of determining geographic or geological affiliation. However, such methods have proven limited when applied in Polynesia (Weisler 1993b). Although the method serves as a first step in the winnowing process, ultimately it is incapable of defining the origin of the source material, and cannot alone definitively account for the possible transfer of raw material (Weisler 1993b).

Petrographic analysis of lithic material has been used by geologists (and subsequently adopted by archaeologists) to source lithic material via microscopic analysis of thin section slides. Petrographic characterization defines lithic material by analyzing its mineral composition. Slides of the unprovenanced material are examined for characteristic geologic attributes that can be traced to previously identified sources.

This method has been utilized on both ceramic and lithic materials in Polynesia (e.g. Cleghorn et al. 1985, Dickinson and Shutler 1979, Weisler 1990).

Although this method can be most effective in eliminating possible sources of lithic material, issues of subjectivity have often plagued its reproducibility (Weisler 1993b, Weisler & Kirch 1996). Subsequently these methodological discrepancies and advances in technology have limited the practice of petrographically sourcing Polynesian stone tools (Best et al. 1992; Weisler 1993a, 1993b). It must be noted that these authors are not suggesting the demise of petrographic analysis in provenance studies, only a preference to geochemical characterization when working with Polynesian fine-grained basalts. It must also be noted that petrographic differentiation may be the only method available in cases of geochemical homogeneity (Rice 1987).

The third and most popular method of provenance study is geochemical characterization. Geochemical characterization defines lithic material by analyzing its chemical composition. It is considered the most powerful, precise and reliable method of sourcing lithic material, and provides the most quantitative and readily reproducible results (Weisler & Kirch 1996). Weisler (1993a: 185) argues for the value of geochemical characterization over petrography because,

> (1) results are reproducible; (2) instrument operating conditions can be reported in full facilitating comparison databases; (3) identification of elements is not subject to human error as with thin-section descriptions; (4) elemental abundances can be reported with precision and accuracy values for specimens and standards; and (5) geochemical sampling locales on specimens more closely

represent the population rather than thin-sections which are limited by two-dimensional surfaces.

These attributes have established geochemical characterization as the touchstone of Polynesian provenance, and a multitude of such research over the past two decades has provided discrete evidence for the transfer of basalts throughout the Pacific (e.g. Allen and Johnson 1997; Best et al. 1992; Weisler 1993a, 1997, 1998, 2002).

Chemical characterization was chosen for this project as the best method of differentiating Tutuilan fine-grained basalt quarries. The technique of chemical characterization chosen for this analysis was instrumental neutron activation analysis (INAA). INAA was chosen for several reasons but first and foremost for its sensitivity. The sensitivity of INAA allows for greater characterization than techniques previously employed in Tutuilan basalt quarry characterization. This sensitivity played an integral role in the successful differentiation of each quarry analyzed, as it detected ample variation between the samples to provide distinct differentiation among the represented quarries.

CHAPTER II

RESEARCH AREA

Geography

American Samoa lies at the heart of the "Polynesian Triangle," over 250 islands that stretch across an expanse of the Pacific ranging from the Hawaiian Islands in the extreme north, Rapa Nui (Easter Island) to the east, and the islands of New Zealand in the southwest (Figure 1). Due to their significant isolation, the islands of Polynesia were some of the last places on the planet to be inhabited by humans. It is a commonly held belief that the Polynesian diaspora began with the colonization of the West Polynesian islands of Samoa and Tonga around 3000 BP by the advancing Lapita culture (Kirch and Green 2001).

The Lapita culture is named for the Lapita site on the island of New Caledonia, one of the first sites that yielded the cultures indicative ornately decorated pottery. Lapita culture spread across East Melanesia and into Western Polynesia some 3500-3000 BP (Kirch 1997). Sites in Samoa and Tonga attributed to Lapita settlements are the oldest sites recorded for all of Polynesia (Burley 1998; Kirch 1997). Although Lapita archaeological sites are undoubtedly the earliest in Polynesia, the attribution of Lapita's role in the development of an Ancestral Polynesian Society is a highly contested subject in Pacific archaeology (see Kirch 1984, 1997; Kirch and Green 2001; Smith 2002). Regardless of their origin, Polynesian navigators advanced across the Pacific. After disembarking from somewhere in Samoa or Tonga these prehistoric seafarers settled

East Polynesian archipelagos, but ultimately advanced north into the Hawaiian Islands and southwest into New Zealand (Kirch 1984). Since initial European contact, the existence of Polynesian societies on lost and isolated shores has captured the imagination of the western academic community. The seemingly impossible task of prehistoric Pacific island colonization has inspired archaeological investigation into the foundation and propagation of Polynesian island societies, investigations often focused on the Western Polynesian island chain of Samoa (Green and Davidson 1969,1974; Kirch and Hunt 1993).

The Samoan archipelago is located at the western fringes of the Polynesian triangle at approximately 14° South Latitude and 170° West Longitude. Just east of the International Dateline, its nine islands of varying size extend approximately 370 km southeasterly. Although islands have been divided politically for over 100 years (Figure 3), the independent nation of Samoa and the unincorporated United States territory of American Samoa have strong cultural ties. Apolima, Manono, Savaii, and Upolu comprise the independent nation of Samoa (previously referred to as Western Samoa). These four major islands represent the majority of Samoan land area. The remaining islands of Manua (Ofu, Olosega, and Tau), the Rose atoll and Tutuila compose American Samoa. Swains Island, some of 320 km northwest of Tutuila, is politically an entity of the territory of U.S. Samoa, however it is not a geologic affiliate of the Samoan archipelago.

Tutuila lies in the center of Samoan island chain (Figure 3). The largest of the American Samoan islands and third largest of the archipelago, Tutuila is a long narrow

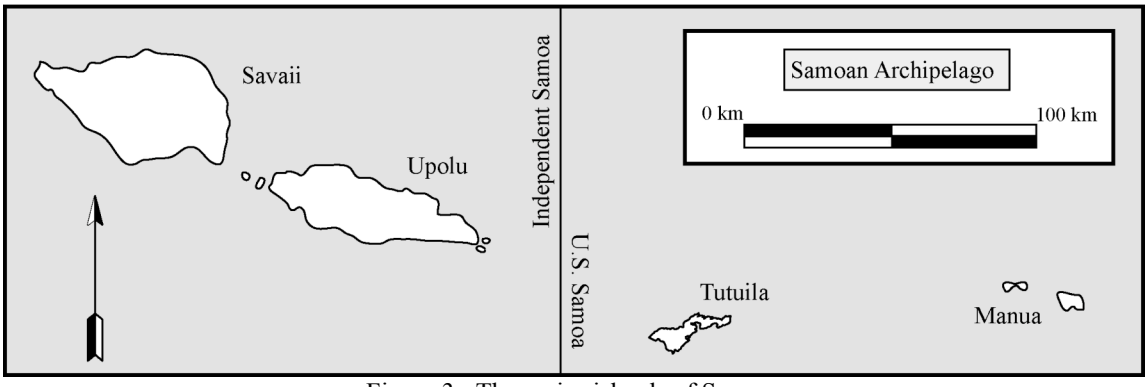

Figure 3. The major islands of Samoa.

landform, bolstered by a spine of steep ridges that supports numerous radiating ridges reaching north and south towards the sea. Taking the shape of a tilted hourglass, its overall length is approximately 31.0 km, but its width varies greatly from nearly 9.8 km at its widest western reaches, to only 1.6 km at its narrowest margins in Pago harbor. The landscape is deeply dissected and marked by broad amphitheater-headed valleys. Severe erosion has carved the jagged landscape from the once gently sloping mountains formed by shield volcanoes. A precipitously abrupt montane backdrop contrasts narrow coastal flats. The steep mountain ridges of inland Tutuila are remnants of the long extinct volcanoes that thrust the island into existence (Stearns 1944). The tallest point on the mountainous island is Matafao Peak at approximately 653 m asl. The only substantial uninterrupted portion of the island is the broad level Tafuna plain. This area of geologically recent origin on the southwestern flank of the island was formed in the Holocene by the post-erosional Leone volcanism.

Geology

The Samoan archipelago lies east of the andesite line (Figure 4). The andesite line is a petrographic boundary that splits the South Pacific into separate geologic divisions. The extrusive rocks found on volcanic islands to either side of the boundary are comprised of distinctly separate igneous composition. The volcanic islands to the east or Pacific side of the island (this includes Samoa and the majority of Polynesian islands) are composed of basalt. The volcanic islands to the west of the line (this includes Tonga and Niue) are all of andesitic composition. This demarcation in petrographic composition is extremely significant in differentiation of lithic artifacts in the Fiji, Samoa, Tonga interaction sphere.

The Samoan archipelago is a series of oceanic basalt shield volcanoes that trend easterly (MacDougall 1985). The shield-building lavas are mostly alkalic olivine basalts and hawaiities that produce fine-grained basalt for lithic manufacture (MacDonald 1968). Samoan shield building volcanism began several million years ago, and ceased around 1 mya. Post erosional volcanism trends against the shield activity, substantially impacting the western islands, especially Savaii (MacDougall 1985; Natland 1980). The western Samoan islands are the oldest and Manua the youngest, although possible rejuvenation of volcanism on Savaii gives the island a deceivingly younger appearance (McDougall 1985; Natland 1980). This more recent volcanism has left much of the shield material inaccessible. Conversely, access to the fine-grained shield material of Tutuila is not seriously impacted by post-erosional flows. Tutuila represents the subaerial remainder of a highly eroded Pleistocene volcanic construct that

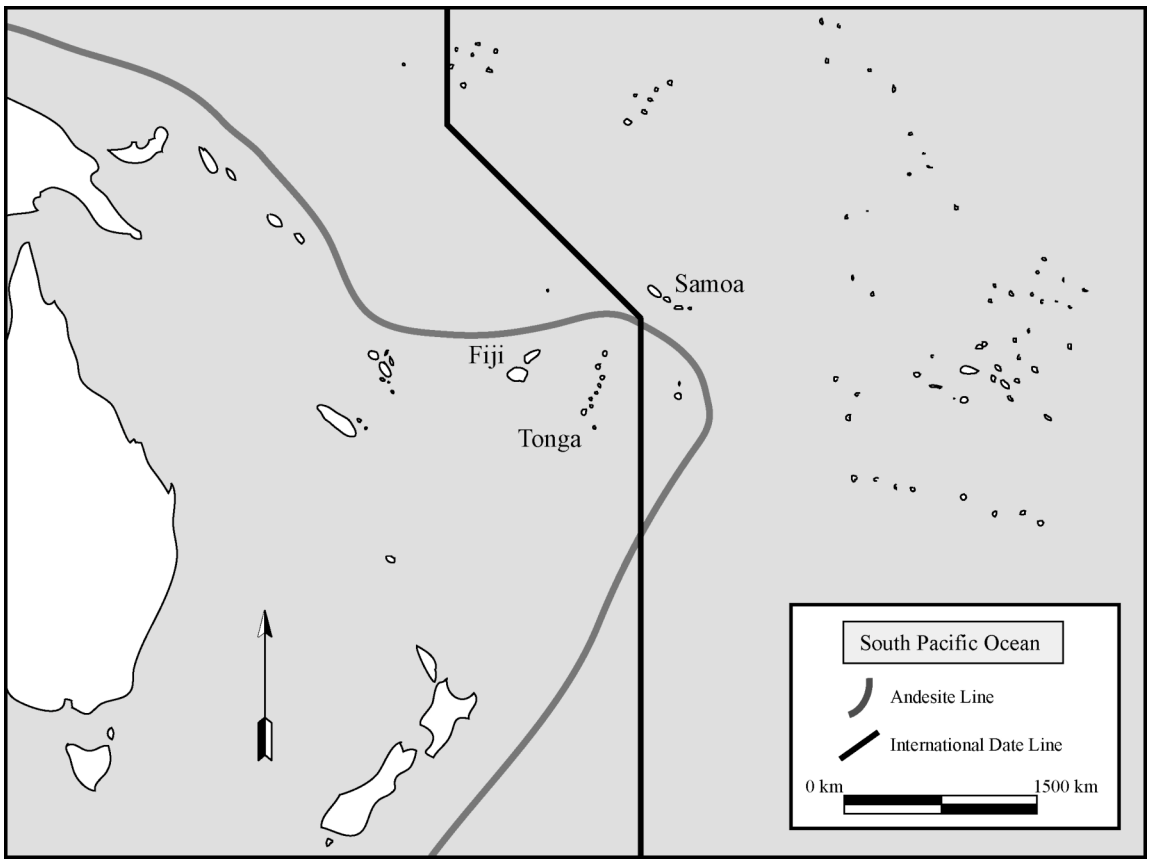

Figure 4. Fiji, Samoa, and Tonga.

formed primarily 1.5 to 1 million years ago (Stearns 1944). Estimates of its original size exceed 1200 m asl, almost twice the height of the present day peak of Matafao.

H.T. Stearns (1944) conducted the seminal comprehensive geologic survey and descriptions of Tutuila. Along with the Stearns work, the *Bulletin of the Geological Society of America* also published the petrographic analyses of Samoa by Gordon A. MacDonald (1944). Stearns (1944) characterized the island of Tutuila as the end product of four major shield volcanic centers: Alofau, Olomoana, Pago, and Taputapu; as well as the more recent post-erosional volcanism represented by the Leone Volcanics

(Figure 5). He proposed that while major shield-building episodes were essentially geologically synchronous, the Olomoana Volcanics were older than Taputapu (Stearns 1944).

Although Stearns's (1944) original study remains a comprehensive analysis of Tutuilan geology, his shield-building chronology has been disputed by more recent interpretations. Natland (1980) proposed that the shield building of Tutuila trended east, with the Taputapu volcanics being the oldest and Olomoana the youngest. In 1985, Ian MacDougall conducted Potassium-argon dating that furthered the argument over the sequence of the island's geologic development. The results of this geochemical dating showed contemporaneous shield-building activity of Pago, Olomoana and Taputapu, and that Olomoana is slightly older than Taputapu (MacDougall 1985). Although the MacDougall (1985) dating supports Stearns' (1944) chronology, it disputes the presence of five distinct volcanic provinces. MacDougall (1985) argues that the Alofau volcanics are not a discrete shield episode, but in fact the "eastern flank" of the central Pago volcano. For the purpose of this project the Alofau volcanics are not considered a distinct volcanic episode, and in accordance to MacDougall (1985) are included in the Pago volcanic province (Figure 5).

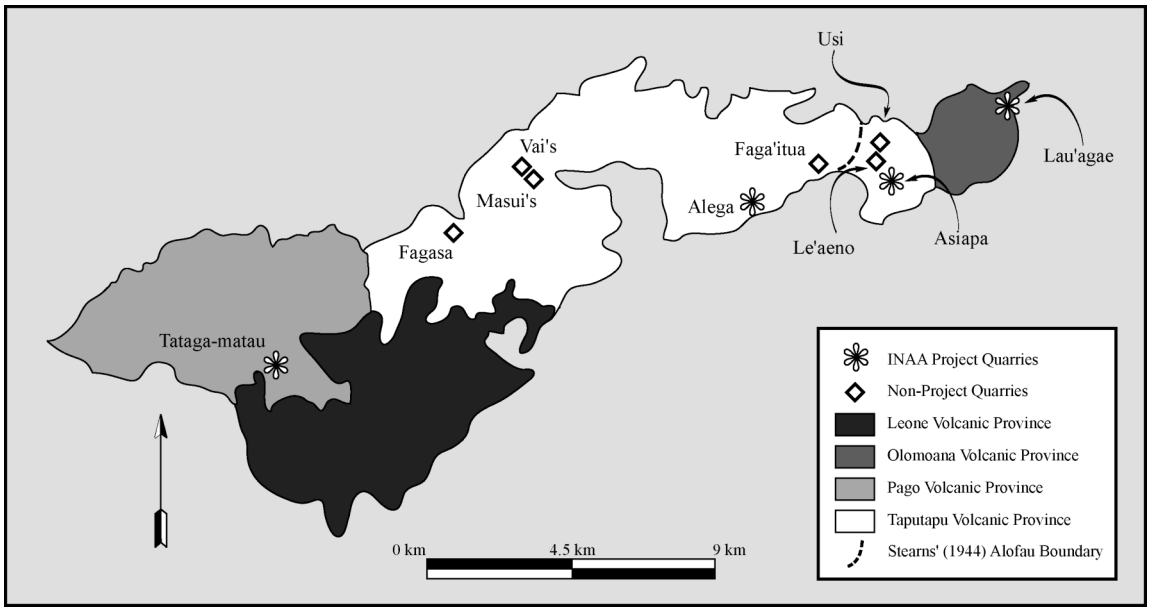

Figure 5. Tutuilan volcanic provinces as described by Stearns (1944) and MacDougall (1985).

Tutuilan Quarries

The term quarry is a somewhat ambiguous when applied to Tutuilan archaeological sites. For the purpose of this project the term "quarry" refers to a prehistoric site of fine-grained basalt exploitation and tool manufacture, and not necessarily to a method of basalt mining. The actual quarrying or mining of material is not probable for most Tutuilan "quarry" sites, with the possible exception of Tataga-matau (Clark et al. 1997; Leach and Witter 1985). In fact throughout Polynesia there is scant evidence to support the extraction of fine-grained basalt for tool making; at most Polynesian quarries the exploited basalt was derived from erosional surface features and dykes (Weisler and Sinton 1997). There are no less than 17-recorded quarry sites on the island of Tutuila (Table 1). Not all possible Tutuilan quarries have received the same

level of scrutiny; some have only been briefly documented (e.g. Clark 1989), while others have undergone more detailed discussions (e.g. Best et al. 1989; Brophy 1986; Clark 1992; Leach and Witter 1985, 1987, 1990; Moore and Kennedy 1996). The following is a brief description of the reported quarry sites on Tutuila (Table 1).

Tataga-matau Quarries. The most well documented quarry location on Tutuila, if not all of Polynesia is the Tataga-matau site. Sir Peter Buck (Te Rangi Hiroa) began the investigation of Tataga-matau in the 1920's. He arrived on Tutuila in 1927 with prior knowledge of Tataga-matau, and was lead to the quarry by the Leone village matai. He stated, "The quarry was well known to the older men who stated that, "people came from all parts of Tutuila to obtain stone adzes at Tataga-matau" (Buck 1930:331). His descriptions of the quarry complex on a ridge above Leone village in western Tutuila would prove the most prominent resource of Samoan quarry investigation over the next half century. Later, Kikuchi (1963) and Clark (1980) revisited the Leone Valley and investigated the location of Tataga-matau, but neither visited the site. Leach & Witter (1985) were the first to rediscover Tataga-matau and comprehensively describe and record the site.

Tataga-matau (AS-34-10) is a complex site located in the Taputapu Volcanics on a ridge spur above the western Tutuilan village of Leone (Figure 4). It was the subject of comprehensive investigations by Leach and Witter (1985, 1987, 1990) and Best and colleagues (1989). The "v"-shaped complex follows along the ridge known as Tataga-matau for several hundred meters, and is delimited on most sides by steeply eroded slopes of 25°to 60° (Best et al. 1989). Tataga-matau is more than a basalt quarry site; it

Table 1. Archaeological fine-grained basalt quarries on Tutuila.

Quarry	Site Number	Location	Province	Size	References
Alega 1	AS-23-22	Alega	Pago	123m^2	(Clark 1992; Clark et al. 1997)
Alega 2	AS-23-23	Alega	Pago	495m^2	(Clark 1992; Clark et al. 1997)
Alega 3	AS-23-29	Alega	Pago	250m^2	(Clark 1992; Clark et al. 1997)
Asiapa	AS-23-31	Alofau	Pago	205m^2	(Clark 1989; Clark et al. 1997)
Fagasa 1	AS-26-10	Fagasa	Pago	27,000m^2	(Best 1993; Clark et al. 1997)
Fagasa 2	AS-26-11	Fagasa	Pago	525m^2	(Best 1993; Clark et al. 1997)
Faga'itua		Faga’itua	Pago	16,000m^2	(Clark 1989; Clark et al. 1997)
Lau'agae	AS-21-100	Tula	Olomoana	10,000m^2	(Clark 1989; Moore and Kennedy 1996)
Le'aeno	AS-21-110	Sa’ilele	Pago	50m^2	(Clark 1989; Clark et al. 1997)
Leafu		Leone	Taputapu	123m^2	(Best et al. 1992; Leach and Witter 1985)
Masui	AS- 25-071	Pago Pago	Pago	-	(report on file at ASHPO)
Tataga-matau 1	AS-34-10	Leone	Taputapu	-	(Best et al. 1989; Leach and Witter 1985,1987)
Tataga-matau 2	AS-34-10	Leone	Taputapu	-	(Best et al. 1989; Leach and Witter 1985,1987)
Tataga-matau 3	AS-34-10	Leone	Taputapu	-	(Best et al. 1989; Leach and Witter 1985,1987)
Usi 1	AS-23-12	Sa’ilele	Pago	70m^2	(Clark 1989; Clark et al. 1997)
Usi 3	AS-23-14	Sa’ilele	Pago	300m^2	(Clark 1989; Clark et al. 1997)
Vai’s	AS- 25-068	Pago Pago	Pago	-	(report on file at ASHPO)

is a complex system of cultural landscape modification. Best and colleagues (1989) describe 13 different types of features at Tataga-matau including but not limited to: terraces, pits (defined both as quarrying and defensive), defensive fortifications, mounds (including star-mounds or *tia ave*, pigeon snaring mounds), three separate lithic quarry sites, and lithic manufacture areas.

Best and colleagues (1992) identify several distinct basalt quarry localities within the Tataga-matau area that likely comprise the Tataga-matau intra-site variability. They refer to this area as a greater "Leone quarry complex" (Best et al. 1992:50). The complex includes the three quarrying areas identified by Best and colleagues (1989) as well as the nearby Leafu quarry subsource situated below the Tataga-matau complex. Samples from the complex were included in this study. Limited access to characterization for this project precluded proper definition of intra-complex variation. With this in mind, it was decided that samples would be collected in order to define a single quarry area. To this end, samples were collected only from Tataga-matau Quarry Area 1.

Alega Quarries. The valley of Alega on the southeast coast contains what remains of several medium sized quarry areas among the Pago Volcanics (Figure 4). In 1992, Clark surveyed the area during an impact assessment for the proposal of a modern basalt quarry in the valley, and reported three quarries on the northern slopes of the valley: Alega 1 (AS-23-22), Alega 2 (AS-23-22), and Alega 3 (AS-23-29). The quarry sites begin at approximately 40 m asl, and continue upslope 10-30 m (Clark 1992).

The largest of the sites reported, Alega 2 was roughly 500 m^2 (Clark 1992). The quarry areas are located on steep slopes (greater than 35°) below a long outcrop. Samples from Alega were included in the project. When collecting samples in November of 2004, the author, accompanied by the landowners and Territorial Archaeologist David Herdrich, of the American Samoa Historic Preservation Office, were unable to relocate Alega 1 or Alega 3. The quarry identified as Alega 1 was most likely destroyed by modern quarrying and construction activities. Although Alega 3 was not threatened by impact from the modern quarry that destroyed Alega 1, it was not relocated and its integrity was not determined. All of the samples collected from the Alega valley were selected from the quarry known as Alega 2.

Asiapa Quarry. On the southeastern ridge near the peak of Asiapa mountain, surveys of the East Tutuila Project discovered the site known as Asiapa quarry (AS-22-31) (Clark 1989). Asiapa quarry is located on the far eastern flank of the island in the Alofau Volcanic Province (Figure 4). The site stretches down the slope of Asiapa peak from approx. 255-239 m asl. Lithic scatter extends across and down the slope covering an area of ca. 205 m^2 (Clark 1989). The author visited the Asiapa quarry with David Herdrich, and collected samples to be included in the project.

Lau'agae Quarry. Located in the Olomoana volcanics (Figure 4), at the farthest eastern reaches of the island on Cape Matatula is the Lau'agae quarry (AS-21-100). This quarry was discovered during the survey of the East Tutuila Project (Clark 1989). Composed of 12 disintegrated areas spread throughout 10,000 m^2 stretched above the village of Tula, the area consists of large primary waste flakes (most with cortex), some

preforms and a few hammerstones (Moore and Kennedy 1996). The lithic debris covers the area in a dense mat, however, no finished tools have been observed. Smaller debitage concentrations indicative of refined shaping are also absent. A number of WWII fortifications have impacted the site. The most obvious impact to the site integrity is a large concrete bunker that is built directly into the uppermost area of the quarry. However, the quarry extends down slope and much of it remains in good condition. Samples were collected from across the Lau'agae quarry to be included in this project.

Faga'itua Quarry. The site is located on the Palapala ridge approximately 400 m above the village of Faga'itua (Figure 4), in the Pago Volcanic Province (Clark et al. 1997). The quarry was first discovered in 1995 after archaeologists followed a substantial basalt flake and tool scatter from Faga'itua. Upon inspection the site proved one of the largest basalt exploitation sites on the island. The site has yet to be fully sampled, surveyed or recorded, but preliminary estimates place its overall size over 10,000 m^2 (Clark et al. 1997). This quarry was not included in the project.

Fagasa Quarries. Perhaps better referred to as a complex of industrial basalt manufacture, the Fagasa quarries are located in the Pago volcanic province on the western slopes of Fagasa Bay (Figure 4). The Fagasa complex (AS-26-10, AS-26-11) is also located in the Pago volcanics. Though the Fagasa quarries are not well documented, it is a substantial series of sites consisting of multiple quarry and manufacturing areas, grinding stones, lithic scatters, terraces, and pits that cover an

mpressive 27,000 m^2 of upland valley floor and ridges (Best 1993; Clark et al. 1997). No samples from Fagasa were collected for this project.

Le'aeno Quarry. Nested in the crown of several peaks, the Le'aeno quarry complex (AS-21-110) is in the center of the eastern mountains in the Pago volcanic province (Figure 4). The quarry locus is on the slope of Sua ridge and is flanked by defensive fortifications in the surrounding peaks (Clark et al. 1997). Although the area is extensive and complex, the quarrying activity represented is nominal and limited to a small portion of the site roughly 50 m^2 (Clark et al. 1997). Le'aeno samples were not collected.

Usi Quarries. North of the Le'aeno quarry lie two small quarries along Usi ridge (Figure 4). The two Usi quarries are larger than the neighboring Le'aeno quarry. Usi 1 (AS-23-12) is approximately 70 m^2, while Usi 2 (AS-23-14) covers a portion of the ridge and slope comprising nearly 300 m^2 (Clark et al. 1997). Neither of the two Usi quarries was sampled for inclusion in this project.

Other Quarry Sites and Possible Quarry Areas. Recently archaeologists from the American Samoa Power Authority archaeology division have located two small quarries above the village of Pago Pago (Figure 4). The quarries were referred to as Masui's quarry (AS-25-071) and Vai's quarry (AS-25-068). There is a small possible quarry locus near Faga'itua that is named Leutele quarry (AS-23-041). Ayres and Eisler (1987) also make the case for the possibility of quarrying activity in the Maloata valley, based on the high frequency of basalt tool material recovered during investigation. Several other sites throughout the island have been suspected of containing quarries, due

to the appearance of grinding stones in streambeds, and tool forms in stream washes (e.g. above Nu'u'uli and Auto villages) (Clark et al. 1997). However, there has been little survey in the uplands since the late 1980's and early 1990s, and much of the area thought to have the highest potential to contain quarries has yet to be surveyed.

Summary

The unique geological and archaeological setting of Tutuila presents a challenging test for artifact provenance research. The basalt quarries of Tutuila create a compelling paradox; in that the close proximity of multiple quarry sites not only presents challenges to the viability of artifact provenance, but ignites significant questions of economy, industry, and interaction that can only be answered through definitive artifact provenance. The lineage of Samoan geological and archaeological research provides the answers to successful characterization of these quarries, and the eventuality of artifact provenance. The geological background for this project was discussed previously; the following chapter elucidates the foundation of archaeological research that lead to this project.

CHAPTER III

PREVIOUS RESEARCH

Samoan Archaeology

Archaeological investigations of Samoa began in the early twentieth century. The first work was mostly survey. In the 1920's the Bishop Museum undertook investigations of the Samoan archipelago. The earliest structured archaeological fieldwork in Samoa was focused on the islands of Western Samoa. Golson (1957 and 1969) guided the first methodological Samoan excavations, on the island of Upolu. Other early Samoan archaeology included Kikuchi (1963), and the seminal work of Green and Davidson (1969, 1974). The Green and Davidson work on Savaii and Upolu created the foundation for all future work in Samoa. Jesse Jennings continued research in Western Samoa in the 1970's (Jennings et al. 1976, Jennings and Holmer 1980). In the late 1970's and 1980's fieldwork in Samoa shifted decidedly to the eastern islands of American Samoa (especially Tutuila). A major impetus for this shift was the establishment of the American Samoa Historic Preservation Office, and a growing need for Section 106 mandated cultural resource management. The influx of federally mandated archaeology created projects on Tutuila, as well as the Manuan islands of Ofu, Olosega and Tau.

Although a great deal of archaeological investigation has been accomplished on Tutuila in the last two decades, limited assessment of montane archaeology has been undertaken. The overwhelming majority of that research was conducted on the coastal

plains, and inland valleys. This is most often due to the search for earliest Polynesian settlements, and possible Lapita sites. Also, difficult accessibility presented by the often exceedingly inhospitable terrain of upland Tutuila deters federally funded infrastructure and leads to the lack of government-sponsored projects in the mountains. The investigations of Best et al. (1989), Clark (1989, 1992), Clark and Herdrich (1993), Frost (1979), Herdrich (1991), Leach and Witter (1985), Moore and Kennedy (1996) and Pearl (2005) represent the bulk of upland archaeological investigation on Tutuila. These upland projects also provide the majority of data on Tutuilan quarry sites, because those quarries are all located on ride tops and mountain slopes. Archaeological investigations of quarries conducted by Best and colleagues (1989), Brophy (1986), and Leach and Witter (1985) were the first comprehensive archaeological evaluations of Tutuilan basalt exploitation, and provided the foundation for questions of provenance.

Samoan Provenance Studies

Chemical characterization of Polynesian lithic material began with investigation of volcanic glass (Smith et al. 1979). In the 1980's Simon Best (1984, 1989) integrated chemical characterization into the analysis of Polynesian basalts. Samoan basalt quarrying inspired some of the earliest efforts in Polynesian geochemical characterization (e.g. Best et al. 1992; Weisler 1993a). The preliminary success of these efforts encouraged a wave of new research throughout Polynesia (e.g. Clark et al. 1997; Parker and Sheppard 1997; Sheppard et al. 1997; Weisler 1993a, 1997, 1998; Weisler and Kirch 1996; Weisler and Woodhead 1995, Weisler et al. 1994). The analytical

methods utilized and discussed in these studies include but are not limited to; x-ray fluorescence (XRF), instrumental neutron activation analysis, and Pb isotope analysis.

X-ray fluorescence was the chemical characterization method most heavily utilized in Polynesian sourcing analysis throughout the 90's. This method gained favor for four key reasons: XRF is less expensive, less time consuming, less destructive and more readily available than most other methods of geochemical characterization. These factors, combined with its successful characterization of Polynesian basalts throughout the Pacific continue to make this method attractive to archaeologists. Throughout the 90's the utilization of XRF flourished in Polynesian provenance studies; establishing spheres of interaction by tracing the movement of fine-grained basalts (e.g. Allen and Johnson 1997; Best et al. 1992; Clark et al. 1997; Parker & Sheppard 1997; Rolett et al. 1997; Sheppard et al. 1997; Weisler 1993a, 1998, 2004; Weisler and Kirch 1996; Weisler et al. 1994).

Some of these XRF provenance studies proposed the interarchipelago transfer of Tutuilan basalt. Allen and Johnson (1997) suspected provenance of Samoan style adzes from the Cooks to uncharacterized quarries on Tutuila. Best et al. (1992) displayed a geochemical affiliation between Samoan style adzes recovered in Fiji and quarry source material from Tataga-matau. Other projects sought to characterize the variability of individual basalt quarries in an effort to document the spatial and temporal distribution of quarry production via artifact provenance (e.g. Best et al. 1992; Weisler 2003a). Although XRF has successfully characterized individual quarry sources and identified

interisland movement of Polynesian basalts, researchers have had more difficulty differentiating between intra-island sources using that technique.

Tutuila presents a unique setting for archaeological investigation of prehistoric basalt exploitation. Several factors have lead to the proposal of Tutuila as an area of industrial basalt tool manufacture meant for interisland exchange: the abundance of known quarry sites; The size and scope of several quarry complexes; and the association of these quarries with large-scale assemblages of stone tool grinding dishes (*fo'aga*) (Best et al. 1993; Clark et al. 1997). The largest, most well-studied, and celebrated Samoan quarry, Tataga-matau, is situated on Tutuila (Best et al. 1989, 1992; Clark et al. 1997; Leach and Witter 1985,1987, 1990). Tutuila has long been thought of as a unique source of fine-grained basalt that was desired throughout the Pacific for its high quality. The missionary Heath (1840) noted in a communication to the weekly Honolulu paper *The Polynesian*,

> that it has been stated that the surface of this group is volcanic, so that the geologist won't find much variety. At Tutuila, however is found the hard stone (Trap,) of which the Polynesian adzes and other tools were made previously to the introduction of iron. At the other islands the stone is almost uniformly porous of a dull black color.

Roger Green (1974) used this historical reference as well as the lack of identified basalt quarries on the islands of Savaii and Upolu as evidence suggesting the infrequency of Samoan fine-grained basalt exploitation.

Relative to other Polynesian islands, Tutuila contains an overwhelming wealth of fine-grained basalt quarry sites. There are 17 recorded quarry sites on Tutuila, including the major quarry complexes of Tataga-matau, Fagasa, and Faga'itua. These vast complexes and concentrations of *fo'aga* have been interpreted as evidence of large-scale pre-contact industrial basalt quarrying and tool manufacture (Clark et al. 1997; Leach and Witter 1985). This industry was certainly too large for Tutuila and likely too large for the entire Samoan archipelago, and probably was developed specifically for trade throughout Polynesia (Best et al. 1992; Clark et al. 1997). This wealth of quarrying sites in close proximity on Tutuila presents a challenging yet ideal opportunity to determine the limitations of characterizing individual Polynesian quarry sites.

The geochemical methods employed to date have succeeded in determining the archipelago or island of origin for Samoan basalts. This level of accuracy is more than suitable for areas and islands with limited basalt resources (see Weisler 1993*c*), however the Samoan archipelago and more specifically the island of Tutuila contain multiple exploited sources. The unique circumstances of Tutuilan quarrying demands further elucidation. Samoan basalt provenance studies would most benefit from definitive quarry level identification of source material and artifacts. Several attempts to provenance basalt tools to Tutuilan quarries (specifically Tataga-matau) have met varying degrees of success (Best et al. 1992, Clark et al. 1997). However, no attempt, to date, has definitively distinguished individual Tutuilan quarries.

In 1993, Marshall Weisler addressed the issue of appropriate scale of provenance studies. He proposed a hierarchy of "geological and artifactual" sampling units

appropriate for answering questions of provenance, the more specific the question the more precise the sampling unit (Weisler 1993*c*: 63). One of the most specific targets of the past decade was sourcing an artifact to the individual quarry of its origin. In response to this quest Weisler (1993*c*: 68) warned, "until most of the major sources of adze material in Polynesia (or a particular study area) have been identified and their chemical variability understood, specifying a particular quarry for each artifact may not be possible".

Before an artifact can be definitively sourced to the Tutuilan quarry of its origin, a comprehensive analysis of each known Tutuilan quarry must be completed to properly define the study area. Numerous studies have linked Tutuila with stone tools recovered throughout the Pacific (e.g. Best et al. 1992; Weisler 1993a, 1993b; Weisler and Kirch 1996). Basalts of Tutuilan origin have been identified as far as 1600km from their source, on Mangaia (Cook islands), an island that contains local utilized basalt sources (Weisler and Kirch 1996). Yet, limited attempts to distinguish intraisland quarry signatures have not displayed definitive separation of all tested Tutuilan quarries (Best et al. 1992, Clark et al. 1997). Identifying quarry level provenance of Tutuilan basalts will allow advanced understanding and interpretation of the intricacies of Samoan socioeconomic and political interactions both within the archipelago and throughout the Pacific. In order to achieve that goal, the rubric of Samoan provenance study must shift.

Tutuilan Geochemical Characterization Studies

To date there have been three substantial attempts towards the chemical characterization of Tutuilan quarries, and the sourcing of artifacts to a quarry of Tutuilan

origin. The most prominent subject of Tutuilan chemical characterization provenance study has been the quarry at Tataga-matau. Both geologic and artifact samples collected from Tataga-matau are included in each of the major attempts at Tutuilan provenance studies: Best and colleagues (1992); Clark and colleagues (1997); Weisler (in Kirch & Hunt 1993). Each of those projects focuses primarily on Tutuilan or Samoan sources. All of these projects utilize XRF in an attempt to characterize Tutuilan quarries and source artifacts with those quarries. Each of these projects varies slightly in both method and purpose. However, the intent of determining Tutuilan quarry provenance was accomplished with varying degrees of success.

Best and colleagues 1992. Best and colleagues (1992) is the compilation of geochemical characterization performed on samples from across the Pacific. In this compilation the authors argued that samples recovered elsewhere in Samoa or across Polynesia clustered favorably with samples used to characterize Tataga-matau. The focus of this paper is an attempt to source artifacts to Tataga-matau. The authors assumed that the basalt exploitation at Tataga-matau was meant for trade beyond Tutuila. The impetus of this project was to determine the spatial and temporal scope of the Tataga-matau basalt trade. Although the project focused mainly on the characterization of Tataga-matau and its possible traded commodities, it remains one of the most prolific attempts at Tutuilan provenance. During the compilation of data for this project very little was known about the scope of Tutuilan quarry sites. It is important to note that until the surveys of the East Tutuila Project (Clark 1989), the

overwhelming majority of currently recorded Tutuilan quarries were yet to be discovered.

In total Best and colleagues (1992) characterized 161 archaeological and geological samples. The sample area for the scope of this project was extremely large, ”bounded by Hawaii, Pitcairn, Easter Island, Tonga, Lau and Samoa” (Best et al. 1992:49). Samples representing islands contained within the geographic constraints of the project design were compiled via donation from various researchers of the particular areas of interest. The donated samples had not been collected specifically for this provenance study. The destructive methods employed for characterization limited the type and amount of samples that were included in the project; due to the reluctance of potential lenders at the prospect of losing irreplaceable material culture (Best et al. 1992).

Samples analyzed were collected from the Samoan islands of Savai’i, Tutuila, Tau, and Upolu (n=68); the Cooks (n=19); the Lau group of Fijian islands (n=9); Henderson (n=1); the Hawaiian Islands (n=13); the Marquesas (n=5); Nupani Island (n=2); Pitcairn (n=12); Pukapuka (n=1); Raiatea (n=1); Rapa Nui (n=2); San Cristobal (n=1); Taumako (n=4); the Tokelaus (n=7); Tonga (n=3); and Tuvalu (n=2) (Best et al. 1992:71-76). All of the samples were analyzed for major elements using XRF at the Department of Geology at the University of Auckland, and 36 samples were further characterized by trace element analysis to confirm contested XRF results (Best et al. 1992).

Of the Tutuilan samples included in the project, 47 were collected from Tataga-matau, and three others from the Taputapu volcanics (Best et al. 1992). The majority of the samples representing Tataga-matau were artifacts, but four were geological samples (Best et al. 1992). The Tataga-matau samples represent various loci across the complex, but the majority was collected from Quarry 1. In addition to Tataga-matau archaeological flakes from Asiapa (n=2), Le'aeno (n=1), and Lau'agae (n=2) were also included (Best et al. 1992:72). Outside of the Tutuilan basalt source material analyzed, Oceanic basalt source material from Hawaii (n=9), Henderson (n=1), the Marquesas (n=4), Pitcairn (n=13), and Rapa Nui (n=2) (Best et al. 1992:63). In total, over half of the samples analyzed were collected from quarry sources and a quarter of the 161 samples were intended to characterize Tataga-matau and the Leone complex. However the majority of the samples were archaeological flakes and artifacts.

In order to interpret the variation of the chemical composition represented within the sample population, the elemental composition of each sample was analyzed using the multivariate statistical methods of average linkage cluster analysis, and stepwise discriminant function analysis (Best et al. 1992). The raw data was transformed (log10) to normalize the distribution. The statistical analyses were carried out using the statistical software SAS (6.01) (Best et al. 1992). Best and colleagues (1992) reported that stepwise discriminant function scores presented (in the following order) CaO, TiO_2, Fe_2O_3, P_2O_5, MnO, SiO_2, MgO, K_2O, and Al_2O_3 as the most distinguishable between the samples. Graphical differentiation was displayed via biplots of phosphorous (P_2O_5) against titanium ($LogTiO_2$) or iron ($LogFe_2O_3$).

The cluster analysis resulted in 17 clusters determined by an average squared Euclidean distance of .05 (Best et al. 1992). Cluster one contained a wide variety of samples (including a majority of the Tutuila samples) and was further subdivided by the authors into four subgroups. The bivariate plots presented display differentiation of samples, and in some cases display differentiation between the Tutuilan quarries that were analyzed. However based upon the small amount of samples that were used to characterize many of the individual sources outside of Tataga-matau (e.g. Asiapa (n=2), Le'aeno (n=1), and Lau'agae (n=2)), the variation of these sources was not properly characterized for comparison against each other. The authors recognized the shortcomings of the sample populations for the quarries included in the project, but were undeterred from proposing artifact provenance.

Ultimately, the results of the analysis did not define Tataga-matau (upper quarry loci) as the dominant quarry of origin of the Polynesian artifacts that were analyzed. However the authors claimed that adequate compositional affiliation was determined between samples to propose a Tutuilan origin for the majority of the typologically Samoan adzes recovered outside of the island; and claim Leone complex origin for many of the artifacts sampled (especially the Fijian adzes) (Best et al. 1992). Given the high number of samples from the Leone complex that were analyzed in comparison to other areas of Tutuila this proposition is problematic. The very low numbers of samples from outside the Taputapu volcanics would not properly characterize the variation of those areas, and therefore would be much more likely to differentiate from other samples analyzed, especially the Taputapu samples. Without the proper characterization of

intraisland variation on Tutuila, claims by Best et al. (1992) of artifact provenance cannot be definitively supported.

The sampling design of Best and colleagues (1992) concentrated on the Leone complex of west Tutuila and failed to define Tutuilan intraisland variation. At the time of the study, many of the currently recorded quarries on Tutuila had not or had only recently been discovered. A few samples from those quarries were integrated into the project, but too few to properly characterize the sources. Without properly defining the variation outside of the Leone complex artifact provenance cannot be achieved at the quarry or local source, or even volcanic province level. The provenance study of Best and colleagues (1992) was the first of its kind in Samoa. Although the sampling strategy proved insufficient for addressing the question of quarry level provenance, the ambitious nature of the analysis was invaluable to the nascent field of Samoan geochemical characterization. The questions posed, data presented and conclusion drawn by Best and colleagues (1992) provided an invaluable foundation for the future of provenance studies on Tutuila.

Weisler 1993a. In 1993 Kirch and Hunt released a report on fieldwork at the To'aga site on the American Samoan island of Ofu. In this volume Dr. Marshall Weisler contributed a chapter on the chemical characterization of artifacts recovered during the excavations. The Weisler (1993a) chapter presents the first provenance study to focus solely on Samoan source material and artifacts. The chapter outlines a provenance study incorporating basalt artifacts recovered on Ofu and Ta'u as well as source material from Mako Ridge and Fa'ala'aga (Ofu) and Tataga-matau on Tutuila (Weisler 1993a). The

samples were analyzed using XRF. The author sought to address two questions of provenance: (1) define variation of basalt artifact composition for the Manuan assemblage; (2) determine if fine-grained basalt from Tataga-matau had contributed to the assemblages from Ofu and Ta'u (Weisler 1993a:168). In addition to questions of provenance, this project served as a pilot test of destructive XRF versus nondestructive ED-XRF (Weisler 1993a).

In total 13 source samples were analyzed from Tataga-matau (n=9), Mako Ridge (n=4), and Fa'ala'aga (n=3). The artifacts selected for analysis were mostly polished flakes that were assumed to be adze fragments (n=22), although unmodified flakes (n=16) were also included to augment the macroscopic variability not wholly represented by the adze fragments (Weisler 1993a). Weisler, as well as Dr. Peter R. Hooper from the University of Washington Department of Geology conducted the XRF analysis in 1989 (Weisler 1993a). Weisler reported the standards for preparation and analysis.

Weisler (1993a) noted that due to the trial nature of ED-XRF on Oceanic basalt artifacts the results could only be considered "semi-quantitative" at that time, and for this reason samples were analyzed by XRF and ED-XRF (Weisler 1993a: 170). Weisler (1993) briefly discusses methods for interpretation of results, including bivariate plots of elements and multivariate statistics. The results of the analysis were not manipulated statistically, and were fully reported in the chapter in tables and graphical displays.

The interpretation of the results was made through elemental ratios: Rb/Sr against Y/Sr, Zr/Sr against Nb/Sr (Weisler 1993a). Weisler proposed that the results

differentiated Tataga-matau and the Manuan sources, and assigned over half of the analyzed artifacts to a probable Tataga-matau provenance (Weisler 1993a). He determined that the results display intrasource variation between Quarries 1 and 3 at Tataga-matau; but conceded that the sample population was too small to be definitive (Weisler 1993a). He stated, "this underscores the need to collect sufficient samples to define geochemical variability of adz quarry resources" (Weisler 1993a: 179).

Although this project was undertaken in the nascent stages of Polynesian provenance studies, it provided a clear and concise design that elegantly tested questions of source and artifact composition variability in Samoa. This project not only tested the variation of Samoan fine-grained basalts, but also the suitability of a new analytical technology (ED-XRF) that had not previously been employed in the characterization of Polynesian basalts and artifacts. Overall the analysis made a contribution to the methodology of Polynesian provenance studies as well as to the database of Samoan quarry characterization and basalt adze provenance.

Clark et al. (1997). The two previous projects, Best and colleagues (1992) as well as Weisler (1993a), represent pioneering attempts at Polynesian basalt provenance studies. These early analyses both centered on questions of Tutuilan provenance (specifically Tataga-matau). During the sample collection and analyses for Best and colleagues (1992) and Weisler (1993a) many Tutuilan quarries were yet undiscovered. With the discoveries of multiple quarries in the late eighties, the landscape of Samoan provenance studies quickly changed. Although a limited number of samples from East Tutuilan quarries were added by Best and colleagues (1992), those quarries were

discovered towards the end of a six year period spent compiling and analyzing samples, and at the time of publication very little was know about the quarries outside of Tataga-matau. Until the quarry discoveries of the East Tutuila Project surveys, Tataga-matau was the only recorded Samoan quarry and was considered possibly the only major source of fine-grained basalt in all of Samoa.

The work of Clark and colleagues (1997) also focused on Tutuilan chemical characterization, but the design and intent differ from Best et al. (1992) and Weisler (1993a). The impetus of Clark and colleagues (1997) was to determine the intraisland variability presented by the multiple quarry sites across Tutuila. The authors revisited the previous efforts of Best and colleagues (1992) and added the analysis of 26 samples representing Tutuilan quarries in an effort to determine intraisland quarry signatures. This project was more material-centered in its design. The impetus of the project was not sourcing artifacts to particular quarries, but to define the variability represented by those separate quarries in an effort to determine the viability of quarry level provenance on Tutuila.

Clark and colleagues (1997) began with a geologic description of Tutuilan volcanic composition. After establishing the geologic variation of the island they presented a synopsis of the Tutuilan quarry landscape (which as previously stated had changed drastically). They briefly described each reported Tutuilan quarry and the prospects of other unreported quarries on the island. They also reported quarry complexes such as Fagasa and Faga'itua that rivaled the size and scope of the venerable Tataga-matau complex. The authors determined an anomalous wealth of quarry sites

and determined that even more sites were most likely yet undiscovered; this evaluation leads to the inference of a basalt export industry on Tutuila (Clark et al. 1997). This background frames the impetus for comprehensive Tutuilan quarry characterization; in that questions of artifact provenance cannot be addressed on Tutuila prior to establishing comprehensive intraisland quarry variation.

To that end Clark and colleagues (1997) analyzed and compared both archaeological and geologic samples from quarries across the island. The samples included were defined by both quarry and volcanic province. The samples included in the project were analyzed by XRF, and those results were compared to data from Tutuila reported by Best et al. (1992) and Weisler (1993a). Eight quarry sites contributed to the samples analyzed as well as seven non-quarry sites for a total of 26 samples from 15 Tutuilan sites (Clark et al. 1997). The eight quarries included were: Asiapa (n=1), Alega 1 (n=1), Alega 3 (n=1), Fagasa (n=10), Le'aeno (n=1), Lau'agae (n=1), Tataga-matau (n=1), Usi 1 (n=1).

The results of the analysis were interpreted by comparison of TiO_2, FeO, CaO, P_2O_5, and K_2O (Clark et al. 1997). The analysis determined ranges in elemental composition of the Samoan quarry material analyzed, but overlap in those ranges between quarries was too great to determine specific quarry signatures. Although some differentiation was evident, the results displayed a significant amount of overlap between quarries. The authors declared,

> attempts to assign artifacts from non-quarry sites to specific quarries on the basis of oxides is premature. Instead, artefact geochemistry is best used to identify the

> island of origin and to eliminate unsuitable source possibilities. Consequently, the statements of Best et al. (1992) regarding the quarry source of numerous artefacts throughout the central Pacific should be regarded as hypotheses, not facts (Clark et al. 1997).

The concerns about quarry level provenance on Tutuila addressed by Clark and colleagues (1997) were valid considering the level of Tutuilan quarry characterization. The compositional overlap between quarry sources displayed the necessity of comprehensive definition of variation within a study area in order to confidently ascribe provenance of an artifact (Weisler 1993b). However the sample size used to characterize the individual quarries was too limited to definitively capture intrasource variation and without definitive intrasource variation it is not possible to define intersource variation.

Although the results of Clark and colleagues (1997) display overlap in quarry composition, more powerful and sensitive analytical methods for analysis (i.e. INAA or ICP-MS), more robust sampling, and application of powerful multivariate statistical techniques could elucidate the problems encountered. With this in mind, claims by the authors that apparent overlap in chemical composition between quarries precludes the differentiation of Tutuilan quarries and subsequent artifact provenance are premature. The design of Clark et al. (1997) most significantly inspired the analyses conducted for this project. It was created to address the problems encountered with definitive differentiation between Tutuilan quarry sources.

Summary

The contents of this chapter (and indeed this thesis in entirety) draw on over a century of Tutuilan research. Each contribution be it geology, geography, or anthropology was integral in the formation of Tutuilan provenance study. Without the contributions towards an understanding of Samoa offered by: the missionary Heath, Sir Peter Buck, Harold Stearns, Gordon MacDonald, Janet Davidson, Roger Green, William Kikuchi, Helen Leach, Daniel Witter, Simon Best, Patrick Kirch, Terry Hunt, Jeffrey Clark, David Herdrich and countless others, the proposition of geochemical provenance analysis of Tutuilan quarries would not exist.

The three pioneering characterization projects discussed, created a substantial foundation for the utilization of chemical characterization in Tutuilan provenance studies. The questions posed and problems encountered served to create and foster geochemical provenance studies throughout Polynesia. These studies together have significantly guided the purpose and method of the research conducted for this project; specifically issues of proper sampling procedures and geochemical techniques were drawn directly from the experience, results and advice of these authors. These contributions are ultimately responsible for the successful propagation of Tutuilan geochemical characterization.

CHAPTER IV

METHODS

Introduction

For this project, basalt samples from four select Tutuilan quarries were analyzed using instrumental neutron activation analysis to determine their elemental signatures. Geochemical analysis of Tutuilan quarries will determine whether intra-island quarry signatures are discernable from each other, and establish a comparative baseline for future reference. All samples included in this project were processed and analyzed at the Texas A&M University Center for Chemical Characterization, under the supervision of Dr. William D. James, of the Elemental Analysis Laboratory. Dr. James performs all archaeometric analysis in close consultation to protocol established by the NSF Archaeometry lab at the Missouri University Research Reactor (MURR).

The state-of-the-art Elemental Analysis Laboratory at Texas A&M University is a component of the Department of Chemistry's Center for Chemical Characterization and Analysis. The laboratory provides research support in the area of elemental and trace analysis as well as service analyses to TAMU users, other university and government agencies and private industry. It is unique in that it features fast neutron activation analysis (FNAA) capabilities in addition to thermal instrumental neutron activation using the University's Nuclear Science Center 1 megawatt research reactor.

Sample Selection

I collected all quarry samples in November of 2004. In addition to my committee, ASHPO territorial archaeologist David Herdrich provided consultation and assistance for the development of specific quarry selection and sampling procedures. The primary purpose of these analyses is to establish geochemical signatures of intra-island quarry sites. A guideline for sample procurement was established to ensure that the geochemistry of each quarry site included for analysis was accurately and adequately represented. This project was designed as a preliminary attempt of defining variation between Tutuilan quarries. With this goal in mind, criteria were established for the quarry selection and sample collection.

Defining the variation of all known quarries on Tutuila was not the goal of this project; as such limitations were placed on the number of quarries sampled in order to succinctly address the design of the project. There were several limitations that were considered when selecting which quarries would be included in this project. The first limitation was the high number of quarries present on the island of Tutuila. There are no less than 17-reported quarry sites on Tutuila (Table 1), and most likely more undiscovered quarries. The number of samples necessary to define the variation of each quarry made it impractical to attempt to characterize all reported quarries.

Time and money were very definitive limitations on the scope of this project. INAA can be a labor and time intensive procedure. Limited monetary funding for this project was allocated from the Texas A&M University Anthropology Department and the American Samoa Historic Preservation Office. The total amount only covered travel

costs associated with a two-week sampling project on Tutuila. That short time frame required a strict and succinct field sampling strategy that could only address the minimum number of quarries required to adequately fulfill the research design.

The INAA process from sample preparation to final analysis can take several months. The actual INAA method takes several weeks to complete each irradiation and gamma ray count. Texas A&M has an active research reactor and access to neutrons must be shared with other projects. The overall length of the analytical process in conjunction with other projects using the reactor can lead to a timeframe of several months for characterization of each quarry. When considering these constraints, unreasonably high sample size could lead to very long delays in the analysis. These limitations along with the costs associated with transport and curation of basalt rock samples made it necessary to restrict quarry inclusion and sample populations to addressing the research design as succinctly as possible.

Considering the aforementioned limitations on the scale of this project, two overarching criteria were chosen to guide quarry selection. The first criterion was that all samples must be selected from quarries that had previously been chemically characterized. Only previously tested quarries were included to allow for the comparison of differentiation results with those previous attempts. Tutuilan quarries that had been previously characterized included: Alega, Asiapa, Faga'itua, Fagasa, Lau'agae, Le'aeno, Tataga-matau, and Usi (Best et al. 1992, Clark et al. 1997, Weisler 1993a, Weisler and Kirch 1996).

The second step in the winnowing process was to choose quarries that were located in separate volcanic episodes. This criterion was motivated as much by an assumption of compositional variation as sample size. It was assumed that the highest order of chemical variation between quarries would be derived by different volcanic origins (Weisler and Sinton 1997). The most obvious method for accomplishing this task was division by Stearns (1944) volcanic provinces. As discussed in Chapter II, each of Stearns (1944) provinces represents an individual shield episode. One quarry was chosen from each of the volcanic provinces, with the exception of the Leone province. No samples were tested from the Leone province because there are no known quarry sources in the Leone volcanics.

The quarries chosen represented three volcanic provinces of Tutuila that contain previously studied quarry sites: Olomoana, Pago, and Taputapu (Stearns 1944, MacDougall 1985). Initially, one quarry from each province was chosen to define possible inter-province variation. A fourth quarry was chosen from the Pago volcanics to test possible intra-province variation. Samples were selected from these four quarries (Table 2). The quarries included: Alega from the Pago Volcanics (n=30), Asiapa also from the Pago Volcanics (n=30), Lau'agae from the Olomoana Volcanics (n=30), and Tataga-matau from the Taputapu Volcanics (n=30). Only fresh geologic samples were used in this analysis because it is a material-centered attempt at defining the quarry

Table 2. Quarries analyzed by INAA.

Quarry	Site Number	Volcanic Province	Sample Size
Alega 2	AS-23-23	Pago	n=30
Asiapa	AS-23-31	Pago	n=30
Lau'agae	AS-21-100	Olomoana	n=30
Tataga-matau 1	AS-34-10	Taputapu	n=30

source variation. Lithic artifacts and debitage found on site were not eligible because they may be intrusive to the site.

I conducted every step of sample selection, preparation and processing from the initial to final procedures involved in this analysis. Sample preparation and processing began in the field. In order for the chemical characterization to be statistically valid, the number of samples analyzed per quarry must be greater than the number of elements (n-1) used in the analysis. The EAL typically reports 28 or 29 elements (based on their significance) in INAA characterization. Consequently, no less than thirty samples were collected and analyzed from each of the four quarries (Table 2).

Samples were chosen from untested boulders that were indicative of material exploited prehistorically. As discussed in Chapter II, the term *quarry* when used to describe Polynesian basalt exploitation is somewhat spurious, in that there is little to no evidence of material excavation in Samoa. Most basalt exploited was surface collected from naturally occurring cobbles and boulders (Leach and Witter 1985, Clark et al.

1997, Weisler and Sinton 1997). Outside of certain areas at Tataga-matau, there is no evidence that suggests extraction of material for lithic tool manufacture at Tutuilan quarry sites (Weisler and Sinton 1997).

Fist sized chunks of basalt were separated from the fresh boulders and labeled. A simple recording method was utilized to minimize confusion. The samples collected were numbered sequentially in order of collection. Every sample collected was numbered in the order that it was collected, from 1-150. Samples 1-30 were collected from Lau'agae, 31-60 were collected at Asiapa, 61-90 were collected from Tataga-matau, and 121-150 were collected at Alega (note that samples 91-120 were collected from a previously unknown and untested quarry in the Pago volcanics. They were not included in this analysis).

The size of each sample collected was also determined ultimately by INAA. Each raw sample must produce at least 200mg of inner (non-cortical and non-weathered) "fresh" material for neutron activation analysis. One ounce is roughly the equivalent of 300,000 mg, so a relatively small sample (the size of a nickel) yields the appropriate amount. However, 200mg is the minimum amount required for initial INAA and is not large enough to fulfill all proper sample size requirements. Proper characterization sampling protocol should allow enough material for several characterizations, petrographic thin section of the sample, and curation for inclusion in future research. To achieve this goal the standard sample size collected in the field was approximately 16 ounces.

Only a small portion of each field sample was required for transport back to Texas A&M. A thumb size portion was chipped away using an Estwing geologic rock hammer and taken to Texas. The remaining portion of the corresponding sample was bagged and tagged and saved for future chemical characterization or petrographic analyses. Those samples are currently being curated at the Jean P. Haydon Museum in Pago Pago, American Samoa.

Sample Processing

Sample processing for INAA was conducted in the Elemental Analysis Laboratory over a four-week period spanning December of 2004 and January of 2005. Once the samples were in the lab, every precaution was taken to eliminate commingling of individual samples. Each individual sample was handled with a fresh pair of sterile Fisher® disposable polygloves. The first step in lab processing was crushing the sample and selecting inner pieces for irradiation. These samples were crushed with a Carver® manual hydraulic press (Model #3912). To minimize sample commingling or contamination as well as loss of material, the samples were crushed in sterile Whirlpaks™ (small sealed plastic bags). The samples were crushed in between two stainless steel plates. The stainless steel plates were washed with distilled water after each sample, and were resurfaced for each quarry.

After the samples were crushed, individual internal pieces were selected using forceps and placed in sterile glass vials. The forceps were washed with distilled water and dried with Kimwipes® delicate task wipers prior to each sample selection. The next step was washing the internal pieces. The pieces were washed in the glass vials using a

combination of acetone and distilled water baths. Initially the pieces were covered with distilled water while in the glass vials. The pieces were agitated to dissolve the dust and dirt into the water. After agitation the water was drained out of the vial. This process was repeated until the distilled water remained clear after agitation. After the dust was removed with distilled water the pieces were bathed in acetone. The acetone was drained and the vials were immediately capped to prevent introduction of dust and dirt.

After the samples were cleaned they were placed in a drying oven to remove all moisture. If any moisture is present during the INAA irradiation it can cause the accumulation of pressure as the moisture vaporizes. This pressure can eventually break the seal on the vial, and ruin the sample. Each sample was dried (in the uncapped glass vial) for 24 consecutive hours in a Blue M® Stabil-therm™ gravity oven at 110°C. Upon removal from the drying oven the samples were allowed to cool, and then weighed and sealed in INAA vials. During sample cooling the glass vials containing the clean, dry samples were placed in a closed desiccator to inhibit moisture accumulation.

The sample size needed for INAA was 50(+/- 5) mg. Pieces were chosen from the glass vials and placed in plastic INAA vials to be weighed. The sample and vial were weighed using a Mettler Toledo Model AX205 balance. Every seventh sample was duplicated as a quality control standard. The balance was linked to a database program, which logged the tare weight of the sample and vial as well as the tare weight of the empty vial. This software automatically logged the weights for each sample and vial into the database, reducing the probability of human data entry error. After each vial was filled with the appropriate amount of sample, it was labeled using an Industrial

Sharpie® marker, and sealed using a soldering iron. The samples were then analyzed using Instrumental Neutron Activation Analysis (INAA) at the Texas A&M Nuclear Science Center's 1 MW TRIGA research reactor.

Instrumental Neutron Activation Analysis (INAA)

INAA is a multi-element analysis technique that can identify trace materials in the range of parts per billion (Neff 2000). With this procedure the sample material is irradiated with neutrons in a nuclear reactor. Stable isotopes in the sample are converted into radioactive (unstable) isotopes, and as they decay they emit different kinds of electromagnetic radiation. After the target nucleus is irradiated it is referred to as a "compound nucleus" (Neff 2000; Glasscock 1992). The compound nucleus is a transitory stage between irradiation and emission of the prompt gamma ray. Upon emission of the prompt gamma ray (γ_p), the compound nucleus is converted to a radioactive isotope (Neff 2000; 1992). During decay the isotope emits a negatively charged beta (β^-) particle and a delayed gamma ray (γ_d) that produces a discrete signature (Glasscock 1992). This signature can be measured to define elemental composition. The delayed gamma radiation (γ_d) is measured using semi-conductor gamma-ray spectrometers. Each element emits gamma radiation of a certain wavelength or energy. Consequently, peaks in the gamma-spectrum at a given wavelength reveal which elements are present in the sample (Neff 2000). The elemental energy levels are counted and reported in parts per million (ppm). This definition of elemental composition of the sample can be used to distinguish samples or group them together. In essence each sample is provided a "signature" for comparison against all other analyzed

samples. These elemental "signatures" allow archaeologists to define the origin of stone tools, through chemical composition of the stone.

INAA is not the only method for chemical characterization of material culture available; however it is the most suitable and proven method for answering the questions posed in this project. INAA is the one of the most sensitive and accurate tools for chemical characterization available to archaeologists. This sensitivity has established INAA as a preferred technique in archaeometric sourcing analyses (Bishop 1990; Neff 2000). According to Neff (2000), INAA is the established "Technique of Choice" for sensitive geochemical analysis. Weisler and Kirch (1996) recognize that the greater sensitivity of INAA in comparison to XRF may be necessary in sourcing of geochemically associated Polynesian basalts. Bishop (1990: 539) also addresses the comparison of XRF and INAA,

> ...in comparison to fully quantitative XRF, INAA is more sensitive and can detect some elements having concentrations as low as a few parts per billion. This sensitivity has contributed to its recognition as the technique of choice by several analysts.

INAA was chosen for two key reasons. First, INAA has greater sensitivity and allows for more accurate and precise characterization of than previously used procedures, thus it has a greater capability to successfully characterize specific Tutuilan quarries (Neff 2000, Weisler and Kirch 1996). The definitive differentiation between quarries may answer long held questions about the significance of particular quarries. Second, and to this point, X-Ray Fluorescence (XRF) analysis has been successfully employed in

determining inter-island variation in South Pacific basalts, but XRF analysis has not definitively characterized Tutuilan intra-island variation. Clark et al. (1997) employed XRF (conducted by XRAL at Michigan State University) in an unsuccessful attempt to distinguish intra-island variation in Tutuilan quarry material. It has been suggested that in the case of defining variation within closely associated Polynesian basalt sources, more sensitive and precise methods than XRF may need to be utilized (Weisler & Kirch 1996). INAA is such a method.

The INAA procedures administered were developed for comparison with results generated at the Missouri University Research Reactor (MURR) Archaeometry Laboratory. Both samples and controls were irradiated and counted. The controls used for these analyses were National Institute for Standards and Technology (NIST) 1633a coal fly ash, and NIST SRM 688 basalt. Due to the variability of half-life decay time between elements, separate durations of irradiation and gamma counts are necessary to account for the maximum chemical characterization (Table 3). Not all elements react uniformly to the irradiation process and subsequently two separate irradiations and three gamma counts were utilized on these samples.

Initially the samples and standards were subjected to a 30 second pneumatic tube (p-tube) irradiation of approximately 10^{13} neutrons per cm^2 per second (10^{13}n cm^{-2} s^{-1}). During this process the samples were transferred into the reactor through a pneumatic tube and irradiated individually. Twenty minutes after p-tube irradiation the samples were counted for Al, Dy, Mg, Mn, Ti and V over a period of 500 seconds. After this initial irradiation and gamma count the samples and controls were irradiated again for a

Table 3. Isotope, energy, and half-life.

Element	Isotope Produced*	Energy (keV)	Half-Life
Short Count (P-tube)			
Aluminum (AL)	^{28}Al	1779.5	2.24m
Dysprosium (DY)	^{165}Dy	94.5	2.33h
Magnesium (Mg)	^{27}Mg	1014.5	9.46m
Manganese (Mn)	^{56}Mn	1811.4	2.58h
Titanium (Ti)	^{51}Ti	319.7	5.76m
Vanadium (V)	^{52}V	1434.1	3.75m
Intermediate Count			
Lanthanum (La)	^{140}La	1596.2	40.27h
Lutetium (Lu)	^{177}Lu	208.4	6.71d
Sodium (Na)	^{24}Na	1368.6	14.96h
Samarium (Sm)	^{153}Sm	103.2	46.27d
†Uranium (U)	^{239}Np	106.1	2.36d
Ytterbium (Yb)	^{175}Yb	396.3	4.19d
Long Count			
Barium (Ba)	^{131}Ba	496.3	11.80d
Cerium (Ce)	^{141}Ce	145.4	32.50d
Chromium (Cr)	^{51}Cr	320.1	27.70d
Cobalt (Co)	^{60}Co	1332.5	5.72y
Europium (Eu)	^{152}Eu	1408.0	13.33y
Hafnium (Hf)	^{181}Hf	482.2	42.39d
Iron (Fe)	^{59}Fe	1099.2	44.50d
Neodymium (Nd)	^{147}Nd	91.1	10.98d
Rubidium (Rb)	^{86}Rb	1076.6	18.66d
Scandium (Sc)	^{46}Sc	889.3	83.31d
Strontium (Sr)	^{85}Sr	514.0	64.84d
Tantalum (Ta)	^{182}Ta	1221.4	114.50d
Terbium (Tb)	^{160}Tb	879.4	72.30d
‡Thorium (Th)	^{233}Pa	312.0	27.00d
Zinc (Zn)	^{65}Zn	1115.6	243.90d
Zirconium (Zr)	^{95}Zr	756.7	64.02d

†(Np) Neptunium is used to detect Uranium
‡(Pa) Protactinium is used to detect Thorium
*Glasscock (1991)

period of 14 hours. During this irradiation multiple samples were analyzed using a rotisserie. The rotisserie held six cans, each can contained eight quarry samples (including a duplicate), two NIST 1633a coal fly ash, one NIST SRM 688 basalt, and a blank. After the long irradiation the samples underwent two gamma counts, called the intermediate and long counts. The intermediate count took place one week after the 14-hour irradiation, and the long count commenced four weeks after the 14-hour irradiation. The intermediate count lasted 2000 seconds and was used to determine the values of La, Lu, Na, Sm, U, and Yb. The long count lasted three hours and detected the gamma radiation from Ba, Ce, Co, Cr, Eu, Fe, Hf, Nd, Rb, Sc, Sr, Ta, Tb, Th, Zn, and Zr. In total 28 elements were identified and analyzed using INAA (Table 3).

Statistical Methodology

Exploratory multivariate statistical methods were applied to INAA results using SPSS version 11 for Mac OSX. These methods are exploratory because they are used to explore the possible affiliation of samples based on compositional variability. Initially, canonical discriminant function analysis (CDA) was used to determine the level of chemical variability between the characterized samples and differentiate between the quarries. This data reduction method enables the consideration of extensive variables that result from multi-element chemical characterization such as INAA. The application of CDA resulted in definitive differentiation between all four-quarry sites. The application of CDA successfully accomplished the goals of quarry differentiation and baseline creation. However, this method cannot be applied to samples of unknown

origin, so would not be applicable as an initial or solitary method of differentiating between unknown samples.

In sourcing projects of unknown sample origin, it is common to initially apply methods of classification such as cluster analysis and principal component analysis (PCA), which are designed to assign group membership to samples of unknown affiliation. Cluster analysis in conjunction with a method such as PCA or CDA is a technique commonly used in provenance studies to establish a baseline against which future archaeological samples could be compared and sourced (Baxter 1994; Glascock 1992). For this reason after the successful initial application of CDA, two methods of classification were applied to the data in order to test them as if they were of unknown origin. The methods, k-means cluster analysis and principal components analysis, were used to determine if these statistical techniques could be used successfully in conjunction with CDA for future artifact centered provenance studies.

Prior to running the discriminant function analysis, all INAA data were log10 transformed (Glasscock 1992). This transformation of data was necessary for two key reasons. First, transformation is necessary with INAA data due to concerns over chemical concentrations that vary by orders of magnitude; some chemical concentrations (major elements) are on the order of 10 times larger than others (trace elements) (Baxter 1994). A logarithmic transformation will normalize the data set and eliminate the discrepancies in orders of magnitude, with the result that all major, minor, and trace element concentrations are give equal weight in the analysis. This is important because it is often the presence of trace elements that define a specific provenance.

Second, transformation is necessary because both discriminant function analysis and principal component analysis assume normal distribution of the data. These statistical techniques will produce spurious results when applied to non-normalized raw data. Log10 transformation of the dataset approximates a normal distribution, allowing for the use of these statistics.

Quarry Differentiation. In previous Tutuilan chemical characterization projects the standard method for determining differentiation between quarries was direct comparison of elements or oxides (Clark et al. 1997; Weisler 1993a). The differentiation of samples based on compositional ratios was displayed through bivariate plots. Although this method of differentiation has been utilized successfully in Polynesian provenance studies, when applied to Tutuilan geochemical characterization it has failed to clearly differentiate between quarries (Clark et al. 1997). This is most likely because differentiating between quarries is driven by more than two or three elements. Considering the problems encountered in previous Tutuilan provenance studies, elemental ratios were not included as a method of differentiation for this project. Rather, k-means cluster analysis was employed to help determine which elements would drive the differentiation of Tutuilan quarry samples.

Classification versus Discrimination. There are two basic methods used to group provenance data: through discrimination and through classification. Both methods are employed in this research. Discriminant methods, such as discriminant function analysis, test group membership of samples with an assigned, or known, origin. Classification

methods, such as cluster analysis, are intended to assign group membership to samples with unknown origin.

Discrimination of different quarry sources was the primary goal of this project. It was assumed that samples collected from each quarry site originated at that site of collection. The intent of this project is not to determine the origin of the samples, but to test the level of variability both within and between the sample populations representing each quarry. This type of statistical question is discriminatory in design not classificatory; discriminant function analysis is the statistical method most appropriate for definition of Tutuilan quarry source differentiation. Shennan (1997:350) describes the application of discriminant function analysis for such purposes as, "One area in which it has found considerable archaeological use is artefact characterization studies, where quantities of trace elements in lithic artefacts or pottery are used to try to discriminate material from different sources."

Canonical Discriminant Function Analysis. Canonical Discriminant function analysis creates a series of functions (one less than the number of assigned groups) that define the maximum variability between the predetermined groups. The first function generated represents the greatest probable variability between the assigned groups; the next function equals the next highest amount, and so on. A biplot of the first two CDA scores graphically illustrates group (in this case quarry) separation much in the same manner as a plot of elemental composition. However, plotting the discriminant function scores defines variation in much greater depth than the bivariate plot of elements.

Discriminant function analysis is a commonly used method in INAA provenance studies and can be used for establishing a baseline for artifact provenance (Glascock 1992). However, because discriminant function analysis alone is not considered a rigorous technique for grouping samples with unknown origins, this statistical technique is usually combined with other techniques (Baxter 1994; Glascock 1992). For the purpose of establishing a definitive baseline for future artifact-centered sourcing studies, k-means cluster analysis and principal component analysis were also applied to the data to increase the rigor of the results. These techniques are commonly used in conjunction with discriminant function analysis in provenance studies (Baxter 1994; Glascock 1992).

K-means Cluster Analysis. Cluster analysis is a method used in provenance studies to assign group membership for samples of unknown origin. Baxter (1994:141) refers to cluster analysis as the "multivariate workhorse in the analysis of chemical composition of artefacts". K-means cluster analysis differs from other methods in that it allows for the definition of cluster amounts (k); but assigning the value of k is not always intuitive and can prove problematic (Baxter 1994). However, for this project, the known number of sampled Tutuilan quarries provides an obvious k value; and since I expect the samples to be assigned by quarry, k-means presents a viable exploratory method of classification.

Principal Component Analysis. Principal component analysis is a very powerful method of exploratory multivariate statistical analysis, and is often used in the interpretation of INAA artifact characterization (Glasscock 1992). PCA is extremely useful at recognizing relationships within the complex and dense data produced by

powerful methods of characterization (i.e. INAA, ICP-MS) (Shennan 1998). PCA produces principal components that maximize the variability present in the sample population. Much like canonical discriminant function analysis, the first component provides the maximum amount of variability; the second represents the next level, and so on. The principal components produced by PCA are a rigorous method of differentiation that can reduce the dimensions of voluminous datasets without substantial loss of data. Much of the variability can be represented in the first three principal components; making PCA a very attractive method for interpretation of INAA data (Glascock 1992).

CHAPTER V

RESULTS

Project

This project tested if individual Tutuilan quarries can be definitively characterized and differentiated using instrumental neutron activation analysis. The ultimate objective of this research is to establish intraisland source variation of Tutuilan quarries providing a preliminary baseline for future artifact-centered endeavors. There are three criteria inherent in the successful completion of this initiative: (1) determine whether geochemical variation in Tutuilan basalts is detectable with INAA; (2) determine whether or not that variation is sufficient to differentiate intraisland quarries; (3) establish preliminary comparable baseline data of Tutuilan quarry variation. Each of the previous criteria was achieved, providing strong support for the accomplishment of the project goal.

Results

INAA was not the solitary method for solving the issues of Tutuilan quarry characterization. Twenty-eight major and trace elements of the basalt samples were analyzed. However the variation represented in the INAA results required interpretation through statistical analysis. The application of multivariate statistical analysis allows for the rigorous inspection and evaluation of variability present in the voluminous data produced by chemical characterization. Several methods were applied to process the variability between the quarries. The primary method for accomplishing differentiation was canonical discriminant function analysis (Table 4).

Table 4. CDA scores for INAA data.

Function	Eigenvalue	Variance	Cumulative	Canonical Correlation
1	29.146	75.4%	75.4%	.983
2	6.979	18.1%	93.5%	.935
3	2.519	6.5%	100.0%	.846

Canonical Discriminant Function Analysis. Canonical discriminant function analysis was used to differentiate between the quarry samples (Table 4). As discussed in Chapter IV, CDA tests the probability of a sample's inclusion in an assigned group versus other available groups. CDA was used primarily to test the first two criteria: (1) whether geochemical variation in Tutuilan basalts is detectable with INAA, (2) whether or not that variation is sufficient to differentiate intraisland quarries. CDA can be used to achieve the third criteria of establishing a baseline for future provenance, but other classificatory methods were also employed for this objective.

Unlike the previous attempts at definitive differentiation of Tutuilan quarries, the INAA characterization reported herein produced clear separation between the samples from each quarry. When analyzed using canonical discriminant function analysis, variation in the 28 elements characterized clearly separate the samples between quarries. Two methods of CDA were applied to the data. The first method analyzes independents together. The second method called stepwise or "jack-knifing" analyzes case by case. The regular CDA method was initially applied to determine group differentiation.

Table 5. CDA quarry source probability.

Sample	Assigned	Alega	Asiapa	Lau'agae	Tataga-matau
PJ003	Lau'agae			90.123%	.987%
PJ008	Lau'agae			99.998%	.002%
PJ065	Tataga-matau			.003%	99.997%
PJ074	Tataga-matau			.001%	99.999%
PJ082	Tataga-matau			.003%	99.997%
PJ085	Tataga-matau			.007%	99.993%
PJ086	Tataga-matau	.001%			99.999%
PJ148	Alega	99.997%			.003%

The results display very clear separation between quarries. The first two discriminant scores created by CDA represent the variability of over 93% of the sample population (Table 4). A biplot of CDA score one and CDA score two clearly displays discrete clusters of samples as assigned by quarry (Figure 6).

In the initial CDA, all thirty samples from each quarry cluster with the appropriately assigned group. The goal for quarry membership was set at 95% probability. Membership probability was set at a high percentage to create a rigorous "core group" of samples for creating a baseline for future reference. The majority of samples (112/120) were assigned with 100% probability to their quarry of origin. Of the 120 samples analyzed only 8 samples were not predicted to quarry membership with 100% probability confidence (Table 5). Although when plotted these eight samples

appear to be possible outliers, they were all predicted to the proper quarry of origin with extremely high probability (99.99%).

After the initial CDA, data was then analyzed using the stepwise method to determine if the samples were appropriately assigned or if certain samples may be unknown (Duff 2002). Using this method only affected the inclusion of one sample. In the initial CDA, sample PJ003 had the lowest probability of quarry membership at 97.25%. Although this was the lowest probability score, it was still very confident and also higher than the 95% established for inclusion in the baseline. However after the application of stepwise CDA the probability of sample PJ003 belonging to Lau'agae quarry dropped significantly to 90.123%. This sample was deemed the only outlier due to a probability score below 95%. Although PJ003 was given 90% of quarry membership, that percentage is starkly contrasted against the other 29 samples which all received scores at or near 100%.

The quarries varied in the amount of separation from each other. Although some quarries were more differentiated than others, all displayed a very strong level of internal cohesion and external separation. Asiapa was the most clearly differentiated quarry. On the biplot of CDA scores one and two, the sample cluster from Asiapa displays the highest level of dissimilarity from the other three quarries (Figure 6). Each of the 30 samples analyzed from Asiapa were successfully predicted to have membership in that group with 100% probability.

Samples from the remaining three quarries, Alega, Lau'agae, and Tataga-matau display less cohesion than Asiapa but maintain distinct definition and differentiation

(Figure 6). Of the thirty samples analyzed from the Lau'agae quarry, 28 samples were predicted with 100% probability. The two samples not predicted at 100% probability were sample PJ003 and PJ008 (Table 5). Both Lau'agae samples were predicted as possible members of Tataga-matau origin. Twenty-nine of the thirty samples analyzed from Alega were predicted as such with 100% probability. Sample PJ148 from Alega had a .00003 probability assignment with Tataga-matau.

Tataga-matau was the least differentiated of the four quarries (Table 5). In total, five of the thirty samples from Tataga-matau displayed levels of probability towards other quarries (Table 5). On the CDA biplot, samples from Tataga-matau strayed from the centroid towards both Lau'agae and Alega clusters (Figure 6). Samples PJ065, PJ074, PJ082, and PJ085 all displayed probability in the hundred thousandths toward Lau'agae. Sample PJ082 displayed 99.999% probability, while a duplicate from the same sample (PJ082A) was predicted at 100% probability. Sample PJ086 displayed 00.001% probability of affiliation with the Alega cluster. Tataga-matau displayed the highest number of samples that were not predicted with 100% probability, but no sample from Tataga-matau had a lower probability prediction than 99.997%.

As displayed on the biplot, three of the four quarries analyzed exhibit significant separation from the others. Asiapa, Alega, and Lau'agae are all clearly defined from each other. These three quarries display significant differentiation between quarries located in the Olomoana and Pago volcanics, as well as significant variation between

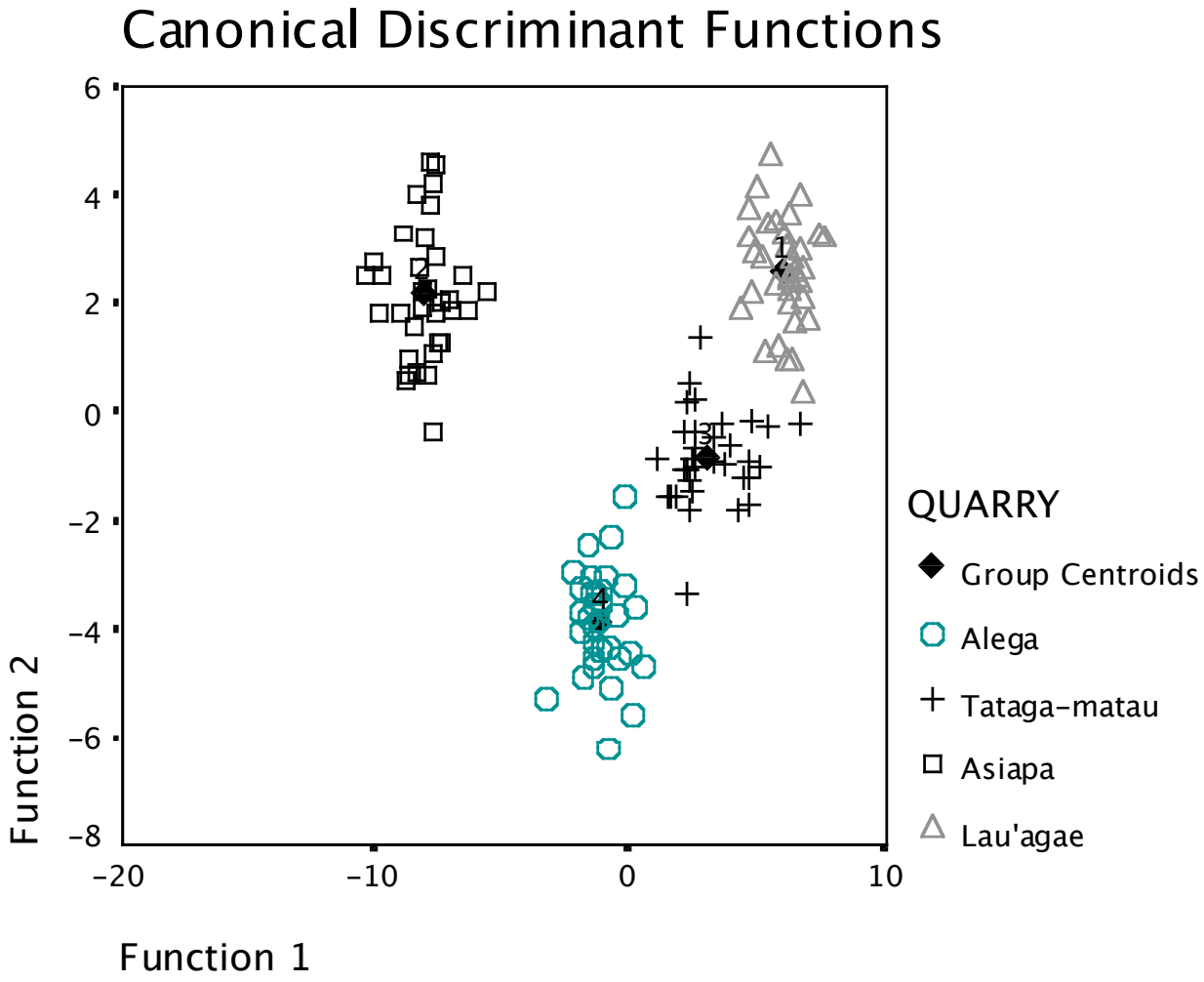

Figure 6. Biplot of CDA scores one and two for INAA data.

quarries within the Pago volcanics. The differentiation for the Tataga-matau samples is much less defined than of the other quarries. In contrast to the variability displayed in chemical composition, Tataga-matau is the most geographically isolated of all the quarries sampled and analyzed. Each of the remaining three quarries (Alega, Asiapa,

Lau'agae) are all located on the eastern portion of the island, while Tataga-matau is conversely located at the extreme western end of Tutuila.

Regardless of the level of variability between Alega, Lau'agae, and Tataga-matau, all of the quarries displayed a clear differentiation when plotted, and the quarry origin of each sample was correctly predicted with extremely high probability (almost statistical certainty for every sample). This differentiation is extremely supportive of the hypothesis. However CDA is not primarily a method for assigning provenance to samples of unknown origin; therefore the baseline it creates is not as rigorous as a baseline created by methods of classification. In addition to CDA, K-means cluster analysis and principal component analysis were also applied to the data in order to assess the application of classificatory methods in the establishment of a baseline.

K-means Cluster Analysis. After successful differentiation through CDA, k-means cluster analysis was applied to the quarry data in order to test how well the samples would differentiate when quarry origin was not assumed. Unlike CDA, cluster analyses are utilized in provenance studies in order to assign group membership to samples of unknown origin. Unfortunately the k-means cluster analysis was not as successful in differentiating between quarries as CDA (Table 6).

The k-means results were indicative of very close chemical composition between quarry sources. This is not surprising because the basalt from each quarry is derived from the same magma chamber. Some samples clustered according to proper quarry of origin while others did not. K-value was assigned as four. All of the samples from Lau'agae clustered together in cluster one, and the samples from Alega and Tataga-

matau were assigned to clusters one, two, and four (Table 6). The mixing of Alega and Tataga-matau is not entirely surprising because those quarries displayed a level of overlap in the CDA results. The most anomalous clustering was from the Asiapa quarry. Of the 30 samples from Alega, 29 clustered together in cluster three. Sample PJ059, was the only sample from Asiapa that did not cluster with the other samples, as it was a clear outlier and the only member of cluster two (Table 6).

Upon inspection of the cluster means and standard deviations it became rather evident why sample PJ059 showed such differentiation. Sample PJ059 contained significantly higher percentages of trace elements Dy, La, Ba, and Ce than the other clusters, although Ba seems to be most influential in driving the separation.
Outliers can skew k-means clustering, so in an effort to redeem quarry differentiation sample PJ059 was removed and the analysis was re-run. Unfortunately the removal of the outlier did not improve the clustering of quarry samples. Conversely, the results without Sample PJ059 were less interpretable than the original effort, as many of the Asiapa samples were commingled with Alega and Tataga-matau.

Beyond the outlier there are two other possible explanations for the unsuccessful application of k-means towards quarry differentiation. The first problem could be the sample size. K-means assumes a large sample population, usually $n > 200$. The sample population may not be large enough for an adequate application of k-means clustering.

Table 6. K-means clusters of INAA data.

Cluster	Samples		Distinguished Elements
Cluster 1	PJ001-030 PJ061 PJ063	PJ067 PJ079 PJ082	Ti 9.567935%+/-540275% Cr .002045%+/-000544% Tb .000675%+/-00071%
Cluster 2	PJ059		Ba .025757%
Cluster 3	PJ031-058 PJ060 PJ081 PJ122-127 PJ128-132	PJ137-138 PJ140-143 PJ145-146 PJ148	Tb .000747%+/-000083% Th .001657%+/-000134%
Cluster 4	PJ062 PJ064-066 PJ068-078 PJ080 PJ083-090 PJ121	PJ133-136 PJ139 PJ144 PJ147 PJ149-150	Yb .001621%+/-000212% Th .002039%+/-00195% Ce .047060%+/-03649%

Although sample size may have contributed to the poor results, the most likely culprit is the method itself. The application of k-means cluster analysis may be problematic due to high compositional affiliation between quarries.

According to Baxter (1994:156), "What the algorithm actually achieves is a dissection into internally cohesive non-overlapping clusters that need not be externally isolated. The restriction to non-overlapping clusters is a possible limitation of the method". Tutuilan quarry samples do not reflect non-overlapping clusters. The chemical characterization of Tutuilan quarries has been reticent in providing differentiation; and has often displayed overlap in elemental composition (Clark et al. 1997). When compared against the CDA bivariate plot this explanation seems more certain. The quarries that displayed the most differentiation (Asiapa and Lau'agae) on the CDA scatter plot display the greatest group cohesion in k-means, and the quarries that displayed the most overlap (Alega and Tataga-matau) on the CDA scatter plot were the most confused by k-means cluster analysis. Ultimately it was most likely the compositional ambiguity between the analyzed quarries that resulted in poor clustering.

Principal Component Analysis. Principal component analysis (PCA) is another exploratory tool used to define variation within a population, and is often used in conjunction with cluster analysis. Principal component analysis is a very powerful method for classifying group membership, commonly employed to differentiate INAA results (Glascock 1992). PCA is similar to CDA in that it conflates the high volume of data produced by INAA and represents the variability of the sample population with a minimal number of scores. It accomplishes this task through a series of principal component scores that are generated to represent the variance within the sample

Table 7. PCA scores for INAA data.

Component	Eigenvalue	Variance	Cumulative
1	15.037	53.703%	53.703%
2	4.017	14.346%	68.048%
3	1.421	5.074%	73.122%
4	1.208	4.315%	77.438%
5	1.061	3.789%	81.227%
6	.840	3.000%	84.227%
7	.817	2.918%	87.146%
8	.612	2.186%	89.332%
9	.518	1.849%	91.181%
10	.382	1.363%	92.544%

population. Like CDA those scores can be plotted against each other to visually display differentiation. When applied to the Tutuilan quarry data, PCA was able to represent over 80% of the quarry variability within the first five scores. This level of variability within the first several principal component scores is substantial. However when the principal component scores for the Tutuilan quarries were plotted the result did not display the same level of differentiation that CDA produced (Figure 7).

This is ambiguity is also most likely explained by a very high correlation of chemical composition between quarries. The first two principal component scores simply do not represent enough variation to differentiate between all quarries. When compared to the CDA results it is evident how the first two discriminant functions

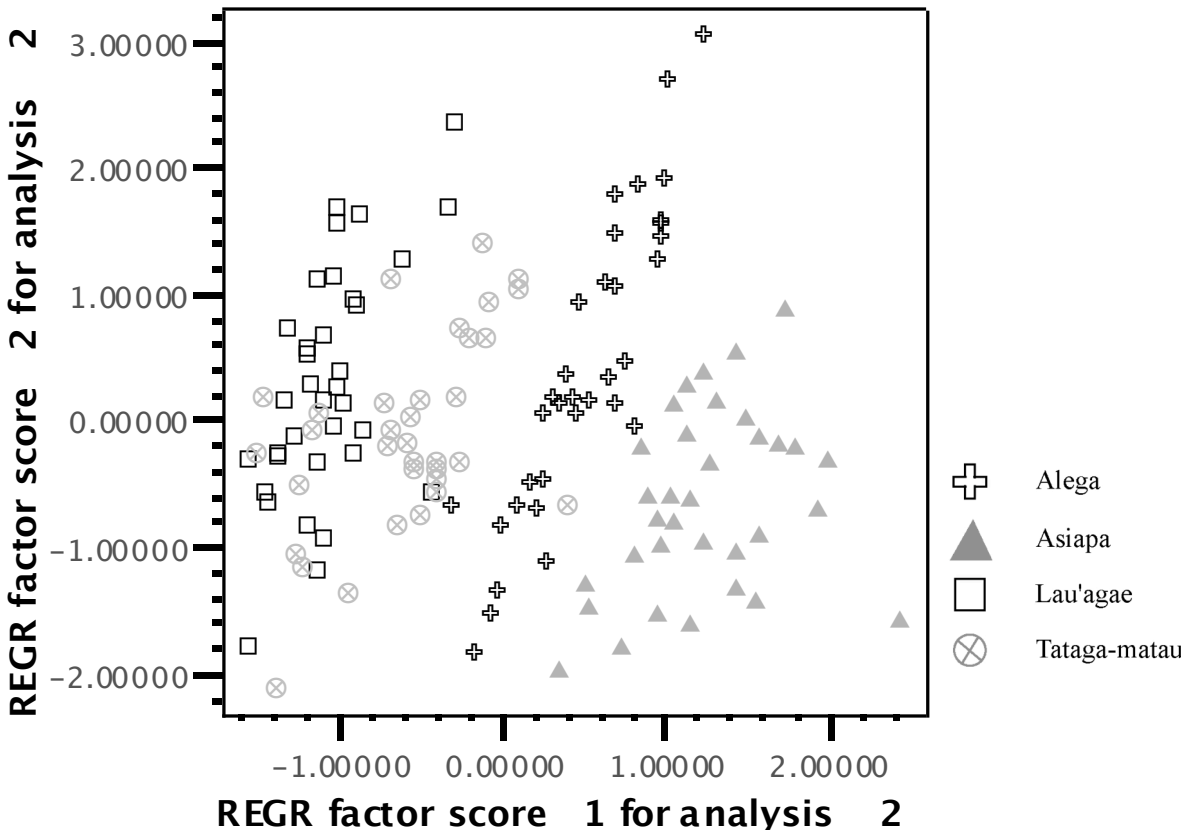

Figure 7. Biplot of first two PCA scores for INAA data.

differentiate between the populations more successfully than the principal components. The first two scores created by CDA represent 93% of the population (Table 4), while the PCA only provides 68% (Table 7). That is a large disparity in the amount of variability and an insufficient amount for differentiation in a sample population of highly similar chemical composition. Although more difficult to interpret; the ambiguity within the bivariate plot of PCA is not indicative to failure of differentiation between quarries. Glascock (1992:18) reports 70% or more of the variance in the first three PCA

scores for INAA data as substantial. When applied to the Tutuilan quarry data, PCA was successful in representing 73% of the variation in the population within the first three principal component scores (Table 7).

The results of INAA characterization clearly differentiate between the quarries; and these empirical data strongly support the overarching goals that inspired this project. However preliminary, the level of differentiation produced by this characterization is extremely encouraging for the application of INAA towards future comprehensive definition of Tutuilan quarry variation, and artifact sourcing. The quarry differentiation achieved through canonical discriminant function analysis provides definitive separation of Tutuilan quarry sources by elemental composition. In accomplishing this task CDA has identified a "core group" of samples that create the preliminary baseline for future artifact-centered provenance studies; and although the differentiation produced by PCA is less perceptible than CDA, the results are encouraging; and further bolstering of the CDA baseline can be achieved by refining the application of PCA.

CHAPTER VI

CONCLUSION AND DISCUSSION

Using compositional data generated with INAA we can now confidently define Tutuilan quarries based on their chemical variability. Unlike the results of prior XRF characterizations, INAA resulted in clear differentiation of all analyzed quarries. Although successful in differentiating the quarries, data compiled in this project suggests that the chemical composition of the quarries analyzed offers a minute amount of interquarry variability. The detectable variability appears limited, but this project clearly displays that Tutuilan intraisland quarry signatures are definable by sensitive and comprehensive methods of analysis such as INAA.

The differentiation displayed in the INAA data illustrates the separation of quarries based on chemical composition. The results of CDA on the data provide 100% probability of proper quarry origin for 112 of the 120 samples. Of the eight samples below 100%, seven received scores of 99.999%, while only sample PJ003 was rejected due to a probability score of 90.123%. The remaining 119 samples create a very confident "core group" of quarry samples, which define quarry differentiation. This "core group" not only defines the individual quarries that are represented, but also establishes a preliminary baseline of quarry variation that can be used in comparative analysis and artifact provenance.

Each of the four quarries analyzed was clearly defined and separated. Both Lau'agae and Asiapa were very clearly differentiated. Based on the statistical analysis of data generated by INAA, it appears that Asiapa and Lau'agae have more cohesion within

their samples, than Alega and Tataga-matau. All methods of statistical analysis employed defined Asiapa and Lau'agae quarries as coherent units. Several Alega and Tataga-matau samples display overlap. The plot of the first two CDA scores illustrates Tataga-matau and Alega samples straying away from their centroids and overlapping into each other and also into Lau'agae. Although they may appear as possible outliers, CDA correctly assigned these samples with a very high amount of probability ($p>99\%$).

Tataga-matau displayed the least amount of cohesion of the four quarries analyzed. The overlap displayed by Tataga-matau is most likely explained by increased source variability that causes elevated intraquarry variation and inhibits quarry differentiation. Best and colleagues (1992) also reported a high amount of internal variability within Tataga-matau samples. Although more sampling is needed for all quarries included in this study, the results of the Tataga-matau data suggest that comprehensive sampling and characterization of all possible intrasite quarry source loci are required to definitively characterize the variation in composition of fine-grained basalt quarries located in the "Leone complex".

The characterization of Tutuilan quarries by INAA has achieved the several objectives associated with successful differentiation outlined in previous chapters. The initial analyses displayed a distinguishable level of variance within the samples that represented each Tutuilan quarry. The variability of quarry samples proved that each quarry sampled displayed more interquarry variability than internal division. This internal cohesion was the integral objective, and provided the basis of quarry differentiation.

The compositional data compiled through this project has not only shown definitive differentiation between the quarries analyzed but it has created a preliminary baseline of data for comparable research. Although the definition of individual quarries is clear, the sample sizes utilized represent the minimum amount for confident differentiation. The baseline created through this project was not intended to be definitive, rather a foundation for expanding the definition of Tutuilan quarry composition. Although the "core group" consists of the minimum samples size appropriate for each quarry, the INAA results display ample clarity in differentiation to provide a proper foundation for artifact-centered provenance studies of the analyzed quarries. The last decade has seen very little activity in Tutuilan provenance study and the intent of this project was not only to address the challenges encountered in Tutuilan quarry characterization but also to develop a worthy contribution for Tutuilan archaeology. I hope the success of this project can provide the impetus for future comprehensive characterizations of Tutuilan basalts and quarries.

Factors for Success

There were three key factors in design that allowed for successful differentiation of Tutuilan quarries. The first factor was sampling strategy. This project was designed first and foremost as a material-centered characterization of quarry variation. Artifact assignment was not a major goal of this analysis; in fact no artifacts were included in the characterization at any point. Previous attempts have included a majority of archaeological flakes in the characterization of the quarry. For this project only raw material was sampled. This sampling strategy was used to ensure that only material

derived at that source was included in the characterization of that source. The high level of cohesion within quarry samples supports this material-centered approach.

Along with sample material, sample size played a key role in the success of this project. In order to define variation in chemical composition between quarries, an adequate amount of samples must be used to first properly define the amount of variation in composition within a particular quarry. This project analyzed thirty samples per quarry in order to define the variation of each source. Although this number was the minimum amount of samples necessary for proper INAA characterization, it represented a much larger population than was attempted in any previous single characterization of geologic samples from Tutuilan quarries. The larger sample size allowed for a more definitive characterization of quarry composition than previously attained.

The final component to the successful characterization of Tutuilan quarries was the method of chemical characterization. Although it has long been successfully utilized in archaeological provenance studies of ceramic vessels and obsidian tools, INAA had not been previously utilized in the characterization of Samoan basalts. INAA is one of the most sensitive, precise and accurate methods of chemical characterization available. Weisler and Kirch (1996:1383) discuss the limits of XRF in characterizing "Oceanic basalts that are highly similar in geochemical composition", and suggest in such cases more sensitive methods such as INAA. This sensitivity was key in differentiation between such highly similar samples.

Caveats

As a preliminary attempt, this project was subject to limitations in both design and intent. While the limited scope was designed to foster the successful completion of the project objectives, it neglected several compelling questions of Tutuilan quarry characterization. The project did not allow for comparison of artifact and geological samples, comprehensive intra-province and inter-province quarry variation, or direct comparison of methods for chemical characterization (e.g. INAA vs. XRF). The data generated from the limited amount of the quarries and samples included in the analysis were intended to create a confident differentiation not a definitive differentiation. The final section includes suggestions towards the clarification of these questions and thoughts on future Tutuilan provenance research.

Future Research

The quarries included in this study were selected to test the ability of INAA to define intraisland variation, not to definitively establish that variation and construct a comprehensive baseline for future reference. As stated earlier there are multiple quarry sources on the island, and the majority were not characterized in this analysis; but the results of the analysis were extremely encouraging for the prospect of differentiating individual quarries on Tutuila. As is often the case of any research project, the answers attained have left room for many other avenues of investigation and much more analysis. The following is a discussion of the type of chemical characterization research that should be conducted on Tutuilan basalts in the future.

Additional Quarries. The first necessary step for future analysis is to sample and characterize the known quarries not included in this project, specifically the major complexes of Fagasa, and Faga'itua. It is necessary to include as many quarries as possible to properly define the variation between each quarry. The preliminary results display a distinguishable amount of variation between quarries, however this trend of differentiation may not continue with the addition of future quarries. At this point it is especially necessary to differentiate quarries within the same volcanic province. As well as addressing the similarity of Tataga-matau (Taputapu) samples with the Pago and Olomoana samples. Addition of more characterized quarries will increase confidence in the definition of variation among Tutuilan quarries. Until all of the known quarries are sampled and analyzed the variation of Tutuilan quarry composition will not confidently account for every possible quarry of origin. This variation must be comprehensively described in order to confidently assign quarry of origin to artifacts. Artifact-centered analyses cannot be considered definitive until this baseline of variation is completed.

Additional Samples. After sampling unanalyzed quarries, the addition of samples from characterized quarries must be included to further elucidate the chemical composition of those sources. The sample size for each quarry was a minimal amount, and more samples must be added to comprehensively define each quarry. The larger the sample population the more confidently we can characterize each quarry. In this project only raw material samples were sampled and analyzed. It was assumed for the purpose of this research that the majority of the flake scatter present at the quarry sites was composed of local material available in naturally occurring surface boulders. Both

material-centered and artifact-centered sampling must be employed to completely define the composition of each quarry. In the future, in addition to raw material, basalt artifacts (flakes, preforms and tools) representing the assemblages present at the quarry sites should also be characterized. This extremely important step will only increase the level of characterization for each quarry as well as offer insight into reduction sequences and material transfer within and between quarries.

Additional Methods. The final suggestion for future sourcing analyses on Tutuila is the comparison of various methods for chemical characterization analyses. The application of alternate methods of analysis towards a material centered characterization of Tutuilan quarries will definitively address the problems encountered in previous characterizations. INAA was the most obvious difference in this project from previous attempts, and its increased sensitivity may have played an integral role in the differentiation of Tutuilan quarries. However the sampling methods applied were also different from other attempts, and the application of XRF and ICP-MS analyses towards a material-centered characterization of Tutuilan quarries will define which method is best suited for differentiating these fine-grained basalts. This question is as important as any others because not all methods are widely available and the definition of each methods ability to distinguish between quarries would allow for the optimal methods to be applied in future provenance studies on Tutuila.

It is my intent to address each of these questions in the future. To that end, Texas A&M offers access to several methods of characterization. The Elemental Analysis Laboratory is extensively used to benefit a wide variety of research programs, reporting

some 50,000 measurements completed each operational year. In addition to INAA, the facility offers access to state of the art Energy Dispersive X-Ray Fluorescence. This allows comparison of the preferred methodology (ED-XRF) in current Polynesian lithic sourcing studies with our NAA results. The laboratory has recently added inductively coupled plasma-mass spectrometry to its stable of facilities. The ICP-MS has been fitted with both conventional sample introduction hardware for solution work as well as a 213 nm laser ablation system for studying solids and surfaces. LA-ICP-MS is a progressive technique that is gaining favor in provenance studies for its power, precision and convenience.

Conclusion

This project represents the foundation for future comprehensive provenance studies of Tutuilan basalts. The differentiation of these four quarries is a necessary step in the comprehensive analysis of Tutuilan basalt exploitation. There are many more quarries both recorded and most likely unrecorded that must be included with this data to create a comprehensive baseline of Tutuilan quarries, but for the first time this data provides a clear indication that differentiation of each quarry is possible. The fine-grained basalt exploitation on Tutuila offers multiple avenues of potential archaeological research, and clear differentiation of quarries is only the beginning. The continued characterization of Tutuilan quarries stands to create a wealth of knowledge and research into the pre-contact interaction, trade and economy of Tutuila and Polynesia.

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APPENDIX

Sample ID	Quarry	AL	DY	MG	MN
PJ001	Lau'agae	103593.1	8.614432	8623.572	1244.87
PJ002	Lau'agae	101127.5	8.571524	7935.981	1307.153
PJ003	Lau'agae	83967.4	11.76493	6685.548	1203.615
PJ004	Lau'agae	87839.55	8.405718	7807.041	1301.978
PJ005	Lau'agae	87286.27	8.553605	7879.173	1334.766
PJ006	Lau'agae	88789.2	7.714061	7893.647	1337.438
PJ007	Lau'agae	89048.67	8.026403	7777.754	1370.06
PJ007A	Lau'agae	89248.68	9.606915	8424.444	1407.534
PJ008	Lau'agae	88266.36	8.342191	8502.146	1380.269
PJ009	Lau'agae	89496	8.320338	8910.644	1296.096
PJ010	Lau'agae	88602.09	6.926753	8704.056	1322.384
PJ011	Lau'agae	89069.15	8.985718	8522.245	1354.213
PJ012	Lau'agae	91975.98	10.0822	8600.608	1309.221
PJ013	Lau'agae	91337.77	8.816865	8622.875	1324.429
PJ014	Lau'agae	93643.8	8.487539	9385.791	1383.125
PJ015	Lau'agae	89176.24	9.30661	8557.947	1322.042
PJ015A	Lau'agae	89905.52	10.31847	9104.894	1349.284
PJ016	Lau'agae	88452.88	9.028753	8962.896	1295.046
PJ017	Lau'agae	89662.04	9.219291	8697.304	1295.291
PJ017A	Lau'agae	90601.94	9.551008	8543.983	1326.553
PJ018	Lau'agae	87602.97	8.752764	9068.778	1297.596
PJ019	Lau'agae	88263.09	9.043925	7857.544	1265.884
PJ020	Lau'agae	87164.73	9.343087	8186.408	1345.781
PJ021	Lau'agae	89783.13	9.025539	8779.283	1309.839
PJ022	Lau'agae	87195.02	8.774449	8522.141	1335.776
PJ022A	Lau'agae	89503.32	9.262108	8385.675	1335.884
PJ023	Lau'agae	86397.04	8.496941	8348.492	1288.566
PJ024	Lau'agae	87253.32	8.724783	8054.593	1299.626
PJ025	Lau'agae	89247.35	8.80715	7863.918	1343.496
PJ026	Lau'agae	90019.2	8.527629	7984.828	1346.214
PJ027	Lau'agae	95817.85	9.457677	9405.233	1444.046
PJ027A	Lau'agae	91620.38	9.298779	8605.146	1392.511
PJ028	Lau'agae	90603.09	8.727729	8285.724	1355.239
PJ029	Lau'agae	90188.97	9.577683	8004.336	1354.382
PJ030	Lau'agae	88465.72	7.686287	8332.247	1345.732
PJ031	Asiapa	87481.66	14.066	6864.208	1629.593
PJ032	Asiapa	85871.34	11.77367	7658.748	1511.064
PJ033	Asiapa	88786.56	12.16324	7228.874	1642.901
PJ034	Asiapa	89904.28	14.24419	7502.745	1711.572
PJ035	Asiapa	96743.56	12.85687	7253.532	1608.169
PJ036	Asiapa	88965.44	11.46207	6732.87	1458.041
PJ037	Asiapa	91269.27	12.21701	7315.895	1442.066
PJ037A	Asiapa	89481.16	13.25916	7070.727	1421.489
PJ038	Asiapa	87198.03	10.73309	6898.252	1495.856
PJ039	Asiapa	85275.48	10.53677	7516.636	1464.288
PJ040	Asiapa	90100.58	12.14243	8115.919	1504.176

Sample ID	TI	V	LA	LU	NA	SM
PJ001	21101.03	234.0031	37.42138	0.3266613	25093.64	11.54212
PJ002	21290.1	266.0918	40.01581	0.336213	26533.81	12.44988
PJ003	25673.26	240.1565	38.67419	0.4994333	26234.18	12.77441
PJ004	22935.15	243.2719	38.29097	0.3451251	26938.04	11.86471
PJ005	23405.19	250.9616	38.23219	0.3339386	26560.64	11.90737
PJ006	23516.45	264.5171	37.80219	0.3096361	25241.71	11.77291
PJ007	23149.28	263.8499	38.001	0.3337617	26181.92	11.85567
PJ007A	23937.29	258.2317	37.47691	0.3195777	25741.32	11.71795
PJ008	23110.07	262.0362	38.01052	0.3122643	27815.71	11.94266
PJ009	24435.73	258.8419	36.33991	0.2883726	25136.57	11.47394
PJ010	24250.99	261.1455	35.55714	0.3118468	23757.73	11.19983
PJ011	24499.77	275.0735	42.04695	0.3350082	30339.14	14.19572
PJ012	25323.27	265.5709	42.76751	0.3719113	30540.65	14.46565
PJ013	25186.43	264.9061	39.07755	0.3512146	27852.14	12.62527
PJ014	25661.59	276.6915	37.71521	0.3136887	27007.69	12.11294
PJ015	23781.1	264.6985	37.25769	0.3086528	24142.85	11.60774
PJ015A	25007.18	273.1953	36.92599	0.3280672	23887.55	11.64057
PJ016	22252.27	248.6911	36.10018	0.2973083	25210.94	11.40617
PJ017	21902.61	256.5324	39.93793	0.3485834	26948.52	12.96427
PJ017A	22900.39	251.8559	38.55423	0.3611591	26943.99	12.27592
PJ018	23603.84	254.0271	36.1348	0.2859197	24423.51	11.3692
PJ019	23711.46	259.3465	37.33423	0.2980029	25162.88	11.71338
PJ020	23725.13	278.3613	38.71866	0.3160082	26472.26	12.32177
PJ021	24617.52	260.2275	36.35072	0.2949735	25235.34	11.74959
PJ022	22596.31	263.2522	37.52108	0.3027848	25617.63	11.74568
PJ022A	22897.87	248.1925	38.64859	0.3170193	24372.65	12.25834
PJ023	22707.99	268.504	39.09155	0.3045028	27061.47	12.34566
PJ024	24554.57	272.5277	37.69933	0.2916592	25775.55	11.98337
PJ025	24593.11	268.9883	38.77689	0.3128722	26164.69	12.22422
PJ026	24609.57	271.6477	36.12762	0.3091265	25620.46	11.39888
PJ027	26666.7	296.4358	36.38339	0.3031536	26158.5	11.49036
PJ027A	24696.97	288.2162	37.29517	0.3287332	27007.54	11.93117
PJ028	25025.04	290.2542	37.70088	0.3329834	26872.39	11.96673
PJ029	24363.47	275.8428	36.77314	0.2980437	25868.71	11.55836
PJ030	23486.1	260.1374	37.77856	0.3110416	25442.87	12.05936
PJ031	17108.46	150.7536	49.56926	0.5684784	28842.02	16.75004
PJ032	18330.13	153.8485	46.61112	0.3811161	28413	15.19872
PJ033	16999.47	169.2509	46.72739	0.4021446	27476.57	15.10211
PJ034	16693.6	155.1707	56.48625	0.5226581	28463.93	18.72984
PJ035	19505.49	173.1599	49.6522	0.4258181	30078.82	16.2947
PJ036	18070.51	156.2887	46.82415	0.3864194	26828.66	15.25316
PJ037	18074.47	149.0038	50.63543	0.4494196	29876.93	16.18805
PJ037A	18191.98	162.5419	48.4918	0.4132255	28960.26	15.40926
PJ038	18419.03	155.6548	47.55334	0.3936365	27569.15	15.62277
PJ039	16757.97	153.7078	45.10239	0.374327	27511.64	14.45001
PJ040	18436.25	159.907	45.35202	0.4073692	26900.08	14.30517

Sample ID	U	YB	BA	CE	CO	CR
PJ001	0.9168611	2.674769	303.3387	87.25641	45.52127	5.163173
PJ002	0.9548294	2.802466	310.4833	83.53108	40.20551	4.957998
PJ003	1.027083	4.148034	266.4084	81.84641	38.67504	4.605841
PJ004	1.022908	2.659499	258.9022	80.13605	37.9851	3.786732
PJ005	1.036078	2.515082	248.5914	79.18859	38.92737	4.705333
PJ006	0.9978818	2.531707	309.7206	84.55211	46.76079	4.608601
PJ007	1.001985	2.575171	281.9514	85.16546	41.36152	4.622026
PJ007A	1.059847	2.574914	275.169	86.81973	41.63538	5.142845
PJ008	0.9649352	2.741623	302.7228	89.18887	42.98196	4.690052
PJ009	0.8322642	2.398627	326.612	96.06779	44.72342	6.941181
PJ010	0.7004295	2.368748	318.481	88.1989	42.52535	4.700502
PJ011	1.080102	2.78782	262.0202	87.92689	43.10046	5.291144
PJ012	0.8815109	2.915258	337.9044	92.84997	45.32427	4.958466
PJ013	0.8926241	2.845618	315.2303	78.71289	39.80666	5.265245
PJ014	0.6119161	2.55232	293.1103	77.59731	38.9507	3.748027
PJ015	0.7817205	2.40626	323.4816	94.97022	49.25523	4.913954
PJ015A	0.8903236	2.405579	250.2252	94.34219	50.43826	5.080551
PJ016	0.7740988	2.536079	257.6814	74.05266	36.25	3.847831
PJ017	0.909517	2.87082	259.9037	83.02775	40.54148	4.614063
PJ017A	0.9305251	3.152052	228.053	76.29575	36.92278	3.687582
PJ018	0.6720139	2.457322	250.2271	90.95773	45.61134	4.357517
PJ019	0.7926558	2.428332	289.9981	80.51014	42.20856	5.495378
PJ020	0.8055561	2.459504	305.7645	84.29744	44.26971	5.098892
PJ021	0.7906749	2.457737	329.2125	79.36646	39.91704	3.7926
PJ022	0.6675224	2.397332	237.7838	85.71663	42.28753	5.339184
PJ022A	0.859938	2.533852	321.9454	102.4066	43.82769	5.088806
PJ023	0.7388205	2.589951	331.3682	87.10358	52.29102	5.209489
PJ024	0.8799091	2.232753	281.2162	81.05236	45.36397	4.352347
PJ025	0.8735511	2.566734	313.1607	88.0516	43.8783	6.557983
PJ026	0.8859842	2.359807	248.6076	83.35203	43.09509	4.940661
PJ027	0.9317114	2.471667	259.2097	81.06818	40.95609	6.616851
PJ027A	0.8735599	2.600404	226.5733	87.76919	43.04945	5.35636
PJ028	0.9786942	2.526824	287.3932	82.29569	44.82639	5.0207
PJ029	0.8872648	2.673934	269.8493	87.55397	43.65054	4.676938
PJ030	1.024361	2.562421	272.4546	85.91792	50.90499	11.26994
PJ031	1.191793	5.002786	351.0549	117.2985	24.61541	2.532516
PJ032	1.162054	3.55901	316.86	113.3609	26.78983	2.94062
PJ033	1.088436	3.529835	295.3219	111.4327	24.79387	2.230855
PJ034	1.545912	4.760939	377.9041	130.1368	28.809	2.647088
PJ035	1.100923	3.702167	330.4006	114.0071	24.82252	2.727755
PJ036	1.246982	3.42049	289.092	114.8988	24.02499	2.729334
PJ037	1.263447	3.565313	336.0645	119.5903	28.15708	2.784627
PJ037A	1.162782	3.450075	289.3027	116.9794	28.55391	3.585294
PJ038	1.2673	3.559407	285.1151	101.9104	23.68031	3.31699
PJ039	1.003937	3.386329	280.2133	100.977	26.3332	1.827121
PJ040	1.130977	3.210971	303.1606	105.2448	25.0132	2.222534

Sample ID	EU	FE	HF	ND	RB	SC
PJ001	3.978342	90644.2	9.396904	43.14233	35.30946	14.59787
PJ002	3.850401	93836.25	9.086885	40.90077	43.44674	13.89924
PJ003	4.363707	89608.59	9.013176	40.96124	45.04267	13.81253
PJ004	3.684921	86530.62	8.886586	38.68779	37.72299	13.32987
PJ005	3.648026	88580.21	8.578942	37.72304	40.05139	13.30734
PJ006	3.889018	90637.88	9.247131	40.15837	40.60709	14.19913
PJ007	3.872105	95341.33	9.47412	39.77003	42.28629	14.1393
PJ007A	3.902733	96156.23	9.452566	41.29612	40.68291	14.37733
PJ008	4.044036	99330.62	9.573784	46.10103	39.60839	14.87803
PJ009	4.315189	104815.6	10.31572	49.28734	33.48605	15.53481
PJ010	4.044275	98271.47	9.733173	43.52593	43.16307	14.47555
PJ011	4.081368	100474.5	9.610972	41.17148	40.16336	14.77917
PJ012	4.227224	104161.9	10.13536	44.21602	45.12312	15.2865
PJ013	3.697704	90743.88	8.61482	39.33314	33.9706	13.47005
PJ014	3.653346	89920.09	8.46787	39.18673	33.66968	13.34256
PJ015	4.289032	105673.5	10.34296	42.74643	47.37812	15.42116
PJ015A	4.288314	104989.5	10.19398	48.14964	49.0689	15.45586
PJ016	3.402424	83190.55	7.996053	33.92059	35.64161	12.32004
PJ017	3.876693	90725.25	9.111296	43.63979	43.85657	13.75329
PJ017A	3.488767	85977.13	8.446225	40.626	40.28955	12.57875
PJ018	4.089512	103254.8	9.421527	48.41227	42.90081	14.9907
PJ019	3.724282	90847.27	8.546945	39.16073	33.86644	13.70286
PJ020	3.895758	95827.56	8.82039	41.75576	33.71529	14.31858
PJ021	3.605584	90150.08	8.358434	39.22091	30.27122	13.52477
PJ022	3.899517	98724.49	8.896985	48.08874	41.2817	14.54777
PJ022A	4.19764	104728.3	11.40758	49.66964	70.61743	15.51754
PJ023	4.05609	100169.3	9.26304	42.81437	44.61787	14.85247
PJ024	3.876521	96552.43	8.591509	40.04701	39.69222	14.19271
PJ025	3.997887	99373.91	9.302867	45.10909	43.53092	14.78586
PJ026	3.863467	92785.87	8.961083	41.03677	37.22069	13.88199
PJ027	3.789555	93382.32	8.596341	39.84148	34.31633	13.78835
PJ027A	4.083145	99227.08	9.514365	44.47678	40.75802	14.73888
PJ028	3.854738	93693.61	8.686314	44.53738	35.45295	13.9031
PJ029	4.057025	97820.94	9.59732	43.62034	43.22923	14.4012
PJ030	3.983388	98918.85	9.376535	44.50037	35.62165	14.29688
PJ031	5.653422	85871.22	10.87817	57.96922	48.70823	12.82508
PJ032	5.16707	89487.16	10.96299	55.99241	49.07187	13.19159
PJ033	5.11215	77589.06	10.91973	55.15176	49.85529	13.01585
PJ034	6.471228	90016.89	11.35619	68.65221	53.76717	13.44042
PJ035	5.209707	83949.95	11.15971	59.02295	48.07757	13.23988
PJ036	5.166864	81534.02	10.7699	52.50986	43.21111	13.06883
PJ037	5.362175	83552.84	11.70976	61.27189	46.3015	13.46443
PJ037A	5.248791	82338.26	11.41069	58.96285	46.92109	13.35217
PJ038	4.782333	80974.73	9.852335	46.1201	43.71926	11.97818
PJ039	4.75169	80587.23	9.99644	51.69242	38.55396	11.91357
PJ040	5.02305	82751.8	10.32263	53.52352	46.42579	12.54068

Sample ID	SR	TA	TB	TH	ZN	ZR
PJ001	715.3226	3.052724	1.621817	3.876062	153.9415	275.8532
PJ002	672.5997	2.842496	1.549878	3.76929	169.1363	260.8402
PJ003	735.3203	2.856544	2.248147	3.658477	174.1512	264.655
PJ004	686.5329	2.857892	1.496701	3.776898	154.0852	272.9948
PJ005	706.8644	2.718519	1.51555	3.612207	161.5733	282.2281
PJ006	749.3164	2.908937	1.577431	3.909956	176.9584	281.1458
PJ007	729.5327	2.902754	1.729958	4.046097	167.5707	275.6585
PJ007A	773.1317	3.006737	1.591319	3.97359	164.1693	256.6397
PJ008	872.8541	3.145324	1.592187	3.896056	183.7091	249.9865
PJ009	898.613	3.158873	1.778937	4.371331	190.9083	231.4302
PJ010	815.9033	2.928977	1.654059	4.024431	168.2411	221.3962
PJ011	995.3014	3.54051	1.774223	4.24849	179.0603	281.4503
PJ012	948.9164	3.610726	1.923408	4.485845	176.9414	295.5411
PJ013	805.8126	3.084792	1.580845	3.737142	151.8458	269.7881
PJ014	793.0113	2.973803	1.629123	3.501121	145.1827	257.5236
PJ015	817.9061	3.178944	1.827175	4.226701	196.1489	270.3668
PJ015A	830.5368	3.172716	1.738213	4.214629	189.9118	195.4052
PJ016	612.9271	2.678289	1.415283	3.443471	147.2975	299.5833
PJ017	774.4297	3.332923	1.731927	3.872033	148.8621	260.1391
PJ017A	847.4182	2.800299	1.462255	3.606342	145.6143	258.7922
PJ018	836.8548	3.169487	1.822569	3.957913	177.4608	276.0079
PJ019	773.7952	2.850671	1.527547	3.67123	174.9554	224.0271
PJ020	864.5761	2.986004	1.754335	3.643704	172.9954	215.4145
PJ021	712.1237	2.849471	1.528475	3.578259	164.3987	252.1522
PJ022	850.0267	3.035877	1.74217	3.786572	173.3312	251.6735
PJ022A	1040.597	3.510531	1.971575	5.13765	181.3449	307.2487
PJ023	924.7617	3.064368	1.720679	3.871001	182.5619	231.0623
PJ024	825.5651	2.873909	1.691576	3.513566	164.3604	236.2513
PJ025	858.8588	3.07868	1.77588	3.793134	187.9362	276.968
PJ026	702.2203	2.883897	1.503497	3.741197	156.5452	249.5381
PJ027	689.8802	2.95833	1.412419	3.442666	156.7635	244.6932
PJ027A	799.7623	3.220292	1.523857	3.903754	166.5306	253.0494
PJ028	717.6668	3.003934	1.425443	3.570546	162.8552	245.7826
PJ029	721.8481	3.180288	1.546143	3.99661	156.7134	319.4594
PJ030	670.2637	3.189315	1.540644	3.95547	156.3791	324.3853
PJ031	735.7671	3.263506	2.315449	4.672407	180.8352	343.9749
PJ032	780.6213	3.298092	2.134395	4.682679	193.9102	343.3344
PJ033	759.5435	3.313616	2.055729	4.663671	215.8874	317.2957
PJ034	774.2939	3.425056	2.727869	4.787824	189.3	334.4485
PJ035	898.7046	3.402307	2.133325	4.768358	216.3797	331.8518
PJ036	843.0479	3.369179	2.134923	4.790919	199.5552	329.9178
PJ037	879.0406	3.537597	2.23855	5.015708	223.3141	355.7123
PJ037A	891.2189	3.455434	2.129834	4.930102	234.7097	320.1395
PJ038	682.8364	3.117839	1.913394	4.394815	190.6926	276.795
PJ039	721.4294	2.702357	1.782579	4.194187	171.1641	345.2628
PJ040	739.3883	2.850674	1.950954	4.322142	176.1589	320.002

Sample ID	Quarry	AL	DY	MG	MN
PJ041	Asiapa	87261.26	11.37881	6941.609	1390.779
PJ042	Asiapa	88489.64	11.73529	7775.438	1431.844
PJ043	Asiapa	91796.83	12.72809	8279.47	1509.525
PJ044	Asiapa	86388.3	13.14902	7198.587	1603.088
PJ045	Asiapa	85814.1	11.38576	6594.113	1326.464
PJ045A	Asiapa	90259.59	11.28545	7810.386	1458.355
PJ046	Asiapa	87885.19	13.71387	7261.396	1407.068
PJ047	Asiapa	87467.7	12.7664	6850.474	1469.357
PJ048	Asiapa	88463.2	12.09393	6836.738	1507.791
PJ049	Asiapa	87961.15	12.81303	6592.873	1374.413
PJ050	Asiapa	87250.23	14.16738	7036.275	1771.276
PJ051	Asiapa	89489.76	13.21724	6489.946	1298.88
PJ052	Asiapa	86484.07	13.83351	6945.797	1574.06
PJ052A	Asiapa	86719.52	13.24197	7376.382	1417.952
PJ053	Asiapa	90035.97	16.54643	6351.004	1308.686
PJ054	Asiapa	91961.27	14.40982	6280.796	2227.059
PJ055	Asiapa	91282.94	13.35461	6975.618	1310.732
PJ056	Asiapa	91828.71	13.12214	6907.135	1283.345
PJ057	Asiapa	92500.48	14.15919	6476.91	1270.453
PJ057A	Asiapa	96680	14.573	6429.399	1258.629
PJ058	Asiapa	88909.18	15.15478	6114.432	1170.139
PJ059	Asiapa	94751.05	18.0732	7250.655	3042.124
PJ060	Asiapa	87491.69	13.55543	7851.156	1398.575
PJ061	Tataga-matau	86528.3	9.027169	7746.205	1502.803
PJ062	Tataga-matau	86829.03	10.84519	8253.447	1457.12
PJ063	Tataga-matau	85101.93	9.190701	8010.022	1471.009
PJ064	Tataga-matau	86641.19	10.13877	8244.758	1349.191
PJ065	Tataga-matau	85597.19	8.543539	8770.763	1365.048
PJ066	Tataga-matau	81878.29	9.680187	8593.893	1405.071
PJ067	Tataga-matau	85011.83	7.826943	8391.063	1315.548
PJ067A	Tataga-matau	83513.38	8.939875	8493.516	1385.811
PJ068	Tataga-matau	84148.85	8.439904	8333.521	1373.772
PJ069	Tataga-matau	84489.77	9.790971	8522.649	1377.407
PJ070	Tataga-matau	89764.31	10.81263	9370.409	1496.347
PJ071	Tataga-matau	91169.1	9.75071	8755.13	1331.115
PJ072	Tataga-matau	87472.22	9.423972	8558.643	1485.36
PJ073	Tataga-matau	91841.45	10.90766	8747.006	1502.732
PJ074	Tataga-matau	90998.2	10.81327	9410.774	1512.612
PJ075	Tataga-matau	93568.08	9.211323	8602.867	1559.19
PJ075A	Tataga-matau	92394.91	10.6829	9295.793	1589.491
PJ076	Tataga-matau	87237.12	9.905013	8486.93	1489.642
PJ077	Tataga-matau	84729.53	10.02771	7543.466	1392.362
PJ078	Tataga-matau	86550.8	10.06376	8044.147	1420.595
PJ079	Tataga-matau	85362.8	9.941364	7971.886	1436.756
PJ080	Tataga-matau	87750.14	9.442072	7865.55	1478.751
PJ081	Tataga-matau	85526.79	11.35499	7287.522	1361.357

Sample ID	TI	V	LA	LU	NA	SM
PJ041	17744.95	144.4008	48.04755	0.383483	28131.38	15.41977
PJ042	16372.55	152.1902	48.7845	0.3866002	29387.64	16.05317
PJ043	17539.87	149.0248	50.48083	0.400939	30185.46	16.78711
PJ044	18400.77	154.4581	50.23187	0.6066685	29740.35	16.93224
PJ045	16841.54	138.1685	46.21522	0.3879274	28416.78	14.97585
PJ045A	17655.07	149.8939	50.58987	0.4271902	31226.48	16.9444
PJ046	18696.52	155.4949	55.80516	0.5876688	28279.27	18.95554
PJ047	18365.64	165.1724	49.62919	0.4248202	25690.3	16.81894
PJ048	18396.12	147.298	49.1425	0.4091694	26571.88	16.16716
PJ049	18900.24	159.1382	51.46991	0.5362141	26531.16	17.53518
PJ050	19472.53	162.2374	55.88842	0.540962	27368.22	18.74087
PJ051	18129.11	150.6097	50.69827	0.4422788	26191.77	16.46426
PJ052	20320.43	202.4636	53.11748	0.4826479	25220.82	17.24245
PJ052A	17618.83	151.8544	56.04802	0.5675814	28206.18	19.00907
PJ053	19672.48	177.7059	64.38538	0.5982842	30683.53	21.46283
PJ054	19316.65	163.794	57.79853	0.5654073	30367.22	19.52953
PJ055	18655.64	152.9448	46.9337	0.4133502	28149.91	15.47266
PJ056	19390.54	163.0943	52.88017	0.6014042	27837.2	17.43982
PJ057	19340.6	164.4574	51.9233	0.4644503	23500.46	17.8419
PJ057A	17928.45	164.3346	54.006	0.5052871	28055.93	19.02437
PJ058	18116.2	153.8798	62.63857	0.5215079	28401.84	20.68862
PJ059	18877.83	169.1779	59.18692	1.176314	28965.85	19.54028
PJ060	18167.98	161.3419	51.20687	0.5200058	29393.6	17.20767
PJ061	23166.43	267.2946	36.29986	0.3112851	22880.51	11.62005
PJ062	22751.65	264.2379	36.77631	0.3175263	23589.23	11.92244
PJ063	22352.42	261.0413	38.30545	0.3459924	24117.17	11.87162
PJ064	22953.55	266.0524	38.51053	0.3505192	24575.67	12.44252
PJ065	23784.46	242.0459	39.41015	0.4061445	26162.84	13.53149
PJ066	21953.47	247.5443	40.99283	0.3956191	26999.13	13.74713
PJ067	22337.18	253.5962	36.01793	0.3126708	23017.32	11.3479
PJ067A	23006.83	270.1158	35.7886	0.3275957	23226.02	11.35981
PJ068	23091.01	251.5413	40.60482	0.4246517	26277.42	13.56253
PJ069	20877.52	233.6206	38.28868	0.3299425	24355.42	11.95911
PJ070	23092.85	254.1223	35.63395	0.317742	22312.79	11.10501
PJ071	23766.83	268.9874	38.25803	0.3359466	24389.49	11.98976
PJ072	21076.43	231.1329	41.64248	0.3845364	26421.49	13.31039
PJ073	22307.68	239.2615	41.4028	0.3804072	26848.14	13.55403
PJ074	22106.31	233.5178	42.0406	0.3873263	26102.93	13.79539
PJ075	22327.2	242.5878	38.96064	0.3350491	24961.1	12.03685
PJ075A	22494.86	247.4171	40.556	0.3799065	26941.72	13.26259
PJ076	22249.77	232.0058	40.58298	0.3842876	28359.92	13.29829
PJ077	21370.75	231.8006	42.00425	0.4028419	29341.33	13.54807
PJ078	21056.11	227.5854	41.59093	0.387479	28744.47	13.63088
PJ079	21644.45	241.5895	39.35653	0.332739	27535.88	12.55058
PJ080	21625	235.9707	43.14853	0.4038535	28815.18	14.14577
PJ081	20843.19	230.8442	52.17887	0.4366572	27616.26	16.20883

Sample ID	U	YB	BA	CE	CO	CR
PJ041	1.046541	3.823918	324.4535	122.8023	29.44951	2.231927
PJ042	1.253756	3.878564	346.1291	118.7491	26.95017	2.597692
PJ043	1.213183	3.790837	357.9194	121.1199	25.99243	2.158496
PJ044	1.220897	5.146131	382.2152	120.5413	26.86581	2.242715
PJ045	1.280189	3.538666	352.2891	118.1938	22.18496	2.445204
PJ045A	1.427705	4.01228	429.0899	121.7	24.57952	1.927461
PJ046	0.9160473	4.809219	295.9857	103.2242	23.032	2.427739
PJ047	0.909986	3.739193	329.4474	114.2944	23.73298	1.848761
PJ048	0.8823475	3.651838	267.3098	106.2963	24.57813	2.473525
PJ049	0.8058484	4.085793	306.3324	115.8722	23.91601	1.592234
PJ050	1.077295	4.810647	372.6702	130.3902	26.9006	2.08502
PJ051	0.9024332	3.811067	283.7917	103.698	21.43978	3.728005
PJ052	0.8899027	4.090102	363.7188	113.298	26.2592	3.11835
PJ052A	1.132492	4.556127	321.1721	113.6145	23.98842	1.364655
PJ053	1.005244	4.984149	337.7424	137.8613	24.66232	3.150341
PJ054	1.274909	4.778631	696.1862	130.2515	27.93124	2.359633
PJ055	0.9207794	3.586987	323.5618	111.7091	22.67917	2.096296
PJ056	1.465615	4.62031	451.847	115.1376	23.93295	2.711106
PJ057	1.097765	3.997173	331.7194	108.1265	22.01745	2.551449
PJ057A	1.803895	4.389179	397.9739	115.6524	21.74973	2.523432
PJ058	1.52756	4.35691	308.384	112.3896	20.95227	3.044314
PJ059	1.62772	8.140633	502.5875	158.7938	30.07965	2.074322
PJ060	1.180749	4.288908	302.2386	107.682	24.43043	2.576143
PJ061	1.045659	2.7149	238.5266	83.65893	42.09324	3.220834
PJ062	0.8526097	2.802177	215.1497	83.0356	45.04826	2.589749
PJ063	1.058356	2.92912	247.2463	95.44717	50.80785	3.448744
PJ064	0.8793167	2.891209	210.5952	87.55379	51.00927	2.99997
PJ065	0.8161761	3.050943	206.293	80.62259	46.80136	2.31087
PJ066	1.042132	3.253342	294.8783	88.19627	42.49681	2.469006
PJ067	0.8484267	2.754803	189.1819	83.96504	46.46325	3.865469
PJ067A	0.8453377	2.77791	194.7808	81.98419	50.8876	3.874194
PJ068	1.036777	2.866823	263.4621	89.56993	42.60904	2.57189
PJ069	0.8272718	2.971815	257.0799	90.24084	36.35381	2.467411
PJ070	0.814938	3.01461	264.1308	81.90854	39.23878	1.848144
PJ071	0.8067344	3.00375	241.8914	76.49834	38.3801	1.904452
PJ072	1.027636	3.265374	253.8889	92.1695	34.41004	2.812002
PJ073	1.011596	3.156551	300.302	93.34824	38.14972	3.658875
PJ074	1.022055	3.372508	348.558	95.42198	38.20184	3.333799
PJ075	0.8556905	3.051528	297.6725	91.2017	35.11077	2.402011
PJ075A	0.9668542	3.231481	331.0017	92.03082	36.51302	2.352141
PJ076	0.9950117	2.901843	252.8149	90.05722	36.19576	2.553096
PJ077	0.9236972	3.107152	297.9137	101.8	37.12806	2.447503
PJ078	0.8405787	3.019978	241.9625	95.17879	41.59866	2.460848
PJ079	0.7527021	3.015296	260.5494	90.81075	35.83731	5.456788
PJ080	1.003924	3.221088	288.7336	104.64	38.0958	2.71147
PJ081	0.9997985	4.040435	326.9122	94.81786	32.13597	2.562675

Sample ID	EU	FE	HF	ND	RB	SC
PJ041	5.492724	89482.5	11.81431	62.74205	46.0535	14.06998
PJ042	5.4622	90253.81	11.59038	60.79153	50.90417	13.76873
PJ043	5.487073	89645.59	12.25801	60.68664	51.66851	13.97097
PJ044	6.043351	91862.25	11.44452	60.92162	51.24279	13.50424
PJ045	5.202653	81679.87	12.36861	60.70398	50.88726	13.25975
PJ045A	5.494307	87136.35	13.13443	61.96703	58.75634	13.92465
PJ046	5.554887	83093.38	10.2513	57.70493	41.75082	12.28696
PJ047	5.552122	87695.1	10.76556	59.09604	46.6074	12.83161
PJ048	4.9767	82441.27	10.45113	53.68047	47.8411	12.49981
PJ049	5.680063	86483.74	10.81347	66.49686	54.24023	12.70549
PJ050	6.379782	91730.2	11.03627	70.37446	51.95574	13.3352
PJ051	5.113634	80473.93	9.992318	51.52838	41.38788	12.03524
PJ052	5.735736	90138.65	10.0901	57.25577	46.9766	11.98725
PJ052A	5.902325	85869.21	10.69532	57.90221	40.68922	12.65037
PJ053	7.536922	93570.73	10.93036	71.83517	50.38945	13.2582
PJ054	6.45757	87294.32	10.4687	69.49385	49.01546	13.02614
PJ055	5.352539	89036.27	10.9179	63.04171	54.02096	13.344
PJ056	5.711215	93769.43	11.56516	64.0042	52.51329	13.84373
PJ057	5.562085	86289.88	10.45678	61.56228	44.36927	12.93319
PJ057A	5.981623	87321.45	10.4076	68.96289	46.27901	13.09089
PJ058	6.645114	86115.88	10.43182	70.35328	45.87028	12.89669
PJ059	6.539545	83311.31	10.77127	66.11082	46.29621	12.46256
PJ060	5.417225	88727.01	10.64326	60.90908	47.21151	13.01296
PJ061	4.051229	96942.38	9.073079	39.22676	34.4057	14.7425
PJ062	4.002494	95355.16	8.835283	36.10485	37.31281	14.76665
PJ063	4.32908	101573.7	10.07914	43.4269	40.25688	15.82705
PJ064	4.178687	92209.79	9.077179	39.4959	31.6683	15.67501
PJ065	3.881463	93904.04	8.848636	39.21017	33.62249	13.70882
PJ066	4.104568	98781.04	9.64391	48.54634	35.24224	15.05299
PJ067	3.978873	90792.76	8.927565	36.77693	33.01682	15.33164
PJ067A	3.971056	99618.76	8.89833	34.78513	34.30846	15.43569
PJ068	4.192306	98293.32	9.703294	43.41344	43.96696	15.23384
PJ069	4.146784	94171.9	9.758655	45.14009	38.77393	14.25461
PJ070	3.804727	92082.81	8.943501	41.50525	35.35716	13.7041
PJ071	3.62443	78999.02	8.495954	37.29351	33.23385	13.2764
PJ072	4.175638	94333.53	9.965693	45.66201	38.18409	13.96532
PJ073	4.379379	97716.97	10.17542	46.79059	41.27645	14.66013
PJ074	4.464511	100917.1	10.42342	47.04372	49.74417	14.82046
PJ075	4.22025	94783.81	9.896996	44.47683	41.83723	14.01878
PJ075A	4.330275	97989.92	9.939599	45.68053	40.20256	14.49743
PJ076	4.227674	96017.1	9.472067	46.04659	35.83276	14.43364
PJ077	4.811203	104693.2	10.7576	51.23632	54.12732	15.44438
PJ078	4.381563	98569.13	10.26717	56.03939	51.20444	15.00325
PJ079	4.203952	93442.11	9.7186	49.22115	44.72996	14.04381
PJ080	4.541835	103670.3	10.72278	53.73403	45.74608	15.66576
PJ081	5.921238	90194.59	9.573667	55.7735	46.50764	13.7744

Sample ID	SR	TA	TB	TH	ZN	ZR
PJ041	806.2199	3.319969	2.188955	5.139606	220.8529	355.3734
PJ042	909.5538	3.349396	2.246284	5.012891	218.2168	335.6339
PJ043	881.981	3.58003	2.287076	5.426195	213.2033	379.267
PJ044	830.5541	3.331078	2.360877	4.985947	195.6299	350.7816
PJ045	815.699	3.165486	2.066723	5.400584	203.0221	379.2587
PJ045A	958.9836	3.728695	2.329969	5.890476	218.2322	384.9665
PJ046	775.0778	3.102504	2.387362	4.466401	164.6835	374.9454
PJ047	832.4224	3.251782	2.370473	4.610247	170.7289	415.0612
PJ048	893.544	3.116067	2.106776	4.583311	177.0383	367.8617
PJ049	810.7683	3.219947	2.348387	4.715376	165.2851	375.8912
PJ050	1050.072	3.167977	2.64783	4.772142	179.8961	435.7977
PJ051	800.9094	2.946516	2.176936	4.324293	161.5212	348.6793
PJ052	761.5919	3.050429	2.311023	4.335176	180.5811	432.071
PJ052A	835.1917	3.04397	2.392603	4.604546	175.3211	452.9582
PJ053	676.6194	3.380997	3.101895	4.809559	197.1186	394.0127
PJ054	792.6766	3.200483	2.536612	4.638213	183.0334	312.2135
PJ055	689.4844	3.214207	2.486828	4.782787	177.4244	331.8561
PJ056	706.4032	3.339746	2.225113	5.147344	203.1684	310.7134
PJ057	489.8345	3.185214	2.138597	4.483912	178.9624	319.0081
PJ057A	697.5954	3.32504	2.455138	4.618503	184.0476	301.5251
PJ058	693.429	3.088621	2.298399	4.475301	163.332	343.6567
PJ059	766.41	3.143965	2.537311	4.870176	173.9282	322.0756
PJ060	700.5043	3.246518	2.308868	4.693029	204.1621	325.8127
PJ061	662.2722	3.00425	1.759724	3.722809	184.073	216.2282
PJ062	617.8761	2.827347	1.552614	3.546779	174.5103	257.6873
PJ063	775.6884	3.201112	1.778283	4.140176	203.6874	286.544
PJ064	780.8899	2.861778	1.677938	3.628671	186.7663	243.9939
PJ065	599.2711	2.617716	1.420976	3.476833	168.8699	236.6971
PJ066	677.8239	2.776075	1.439237	3.917499	181.5003	239.8914
PJ067	645.8955	2.871157	1.579369	3.615497	175.1034	235.5415
PJ067A	717.6212	2.794072	1.558061	3.588565	183.4383	286.9998
PJ068	622.2806	2.813826	1.553899	3.902546	189.0966	256.9446
PJ069	739.051	2.900071	1.811689	3.89824	177.9047	292.9337
PJ070	613.6057	2.63794	1.576142	3.582436	156.6264	283.8209
PJ071	542.8595	2.499893	1.512219	3.320952	153.4783	261.2488
PJ072	736.7759	2.909646	1.74909	4.02637	168.6005	341.5638
PJ073	806.8783	3.223246	1.911399	4.178899	198.235	319.6792
PJ074	812.4423	3.456498	1.967216	4.342361	177.9143	314.2045
PJ075	703.0966	2.987952	1.779299	3.972422	171.804	313.1458
PJ075A	774.4849	3.048203	1.883296	4.068806	176.8712	343.0926
PJ076	685.6666	2.93744	1.929014	3.822123	169.0704	266.0534
PJ077	778.4755	3.159731	2.101348	4.424247	187.8009	282.3219
PJ078	704.1603	3.165477	2.043867	4.264946	194.4247	293.747
PJ079	685.156	2.93696	1.989381	3.87327	188.5801	266.5406
PJ080	751.1576	3.346781	1.959729	4.485516	194.7559	320.5299
PJ081	722.2577	3.023581	2.072437	3.894909	166.278	297.0659

Sample ID	Quarry	AL	DY	MG	MN
PJ082	Tataga-matau	87404.2	9.217237	7705.673	1421.714
PJ082A	Tataga-matau	85706.84	10.18171	8078.75	1422.832
PJ083	Tataga-matau	85415.31	10.78941	8272.821	1428.157
PJ084	Tataga-matau	86722.56	10.55731	7600.147	1446.728
PJ085	Tataga-matau	90131.59	9.843244	7667.241	1577.423
PJ086	Tataga-matau	86828.3	10.07465	8031.604	1469.787
PJ087	Tataga-matau	89948.78	11.29526	8435.183	1411.415
PJ087A	Tataga-matau	85833.27	9.829774	8830.174	1451.317
PJ088	Tataga-matau	87638.84	10.76591	8205.239	1464.584
PJ089	Tataga-matau	87882.69	9.983201	8599.488	1479.028
PJ090	Tataga-matau	88016.64	11.06241	8239.821	1523.943
PJ121	Alega	88314.99	9.943774	7262.306	1298.458
PJ122	Alega	95610.73	11.80233	7787.41	1369.068
PJ123	Alega	88526.84	10.40001	7844.795	1358.158
PJ124	Alega	88808.81	11.72633	6919.092	1419.517
PJ125	Alega	85101.75	10.51945	7396.427	1342.957
PJ126	Alega	86024.13	10.21914	6904.727	1316.23
PJ127	Alega	87751.34	10.22266	7453.518	1416.268
PJ127A	Alega	86529.21	11.24408	7375.039	1413.067
PJ128	Alega	87169.65	10.16363	7256.332	1339.542
PJ129	Alega	93880.3	11.03002	8161.806	1343.889
PJ130	Alega	89680.63	11.15208	8290.478	1420.599
PJ131	Alega	94981.34	11.61259	8273.968	1398.812
PJ132	Alega	92042.88	11.40056	8770.895	1470.337
PJ133	Alega	92336.49	11.67792	7627.841	1394.424
PJ134	Alega	94023.21	11.47258	8560.734	1491.504
PJ135	Alega	89320.3	13.16629	6803.526	1305.576
PJ135A	Alega	89002.58	11.42764	7704.551	1323.073
PJ136	Alega	89573.07	11.66322	7620.05	1511.93
PJ137	Alega	89565.19	11.37716	6890.715	1276.459
PJ138	Alega	90698.49	11.50528	7386.517	1624.998
PJ139	Alega	88103.69	9.941649	7154.08	1272.827
PJ140	Alega	90394.93	12.80916	7399.984	1343.086
PJ141	Alega	88659.9	10.6956	7757	1415.502
PJ142	Alega	88511.73	12.14873	7358.55	1321.022
PJ142A	Alega	89139.84	12.25578	7730.74	1467.461
PJ143	Alega	87076.74	12.04629	6709.498	1296.741
PJ144	Alega	87264.23	10.98996	7462.852	1406.964
PJ145	Alega	90323.38	11.11863	7312.353	1361.109
PJ146	Alega	88443.59	11.82853	7656.521	1471.542
PJ147	Alega	88814.11	11.36365	6801.233	1396.427
PJ147A	Alega	90260.13	11.03108	7843.463	1492.7
PJ148	Alega	91062.29	11.46646	7504.435	1400.571
PJ149	Alega	92610.74	12.40679	7396.205	1316.908
PJ150	Alega	92407.36	11.88924	7549.769	1425.39

Sample ID	TI	V	LA	LU	NA	SM
PJ082	20663.91	233.5496	40.58016	0.3705439	29741.72	13.42944
PJ082A	20785.51	235.0383	38.51662	0.3349193	28041.37	12.59373
PJ083	22271.5	235.6648	39.35376	0.3600995	26243.34	12.41156
PJ084	21070.53	235.0274	41.99007	0.4045187	28018.85	13.26362
PJ085	22499.99	231.0926	39.81864	0.3944757	27157.87	12.64572
PJ086	20964.46	223.2053	42.04315	0.3877606	26810.98	13.55968
PJ087	21861.13	240.1296	40.10366	0.3851629	25686.65	12.86787
PJ087A	21530.75	226.7193	39.96626	0.3540632	25599.71	12.51399
PJ088	21460.35	234.0149	40.14381	0.3824475	25854.18	12.90019
PJ089	20925.75	240.7761	42.07108	0.4028022	27579.44	12.9638
PJ090	21814.18	238.3129	39.69025	0.3698358	26991.47	13.11213
PJ121	21028.96	210.7318	50.7921	0.4863977	30989.34	17.26819
PJ122	23060.69	231.3521	53.81631	0.5104916	23794.18	19.00446
PJ123	18866.55	193.7261	48.46206	0.4921339	30161.39	16.99189
PJ124	20699.46	203.8573	46.27272	0.420145	26347.71	15.5141
PJ125	19285.13	198.6015	46.1413	0.4164513	28390.15	15.52899
PJ126	19338.07	194.3692	45.31361	0.4117357	27456.41	15.44755
PJ127	19875.24	211.05	45.21473	0.455856	27277.32	15.28212
PJ127A	19322.82	200.0674	47.47202	0.4724179	28759.72	17.00613
PJ128	20523.64	205.692	48.3332	0.4687716	28585.64	16.19559
PJ129	20660.61	208.7995	47.75814	0.476035	29103.72	15.80474
PJ130	20283.55	217.3921	50.42529	0.478141	31396.52	17.20703
PJ131	20452.33	219.7269	47.76506	0.4392646	27292.44	15.70952
PJ132	20748.43	211.0251	44.98391	0.4430532	27850.07	14.80551
PJ133	18859.01	206.0767	43.7933	0.4628148	25606.53	13.54367
PJ134	20599.91	221.8493	39.78457	0.383986	25617.59	12.97654
PJ135	18345.84	192.5502	49.58316	0.4500678	27929.05	16.13224
PJ135A	19232.8	200.4239	42.26876	0.4062194	26514.26	13.76732
PJ136	20612.39	213.6825	42.88699	0.4301684	27972.48	13.66194
PJ137	19855.16	220.7686	42.95404	0.3907521	26111.83	14.2394
PJ138	20274.53	219.9082	46.83146	0.4524244	25774.19	14.99084
PJ139	20397.27	221.7509	43.98143	0.4396277	27224.14	14.07958
PJ140	20051.73	213.5027	48.97282	0.4497339	25701.96	15.23248
PJ141	21196.03	209.6862	45.10997	0.4252483	27312.21	14.33818
PJ142	19709.01	207.3625	46.25856	0.4572251	28291.98	14.91046
PJ142A	20360.54	233.2148	48.43875	0.4834167	27711.68	15.59648
PJ143	19636.32	206.0507	45.92916	0.4803697	27811.62	14.98665
PJ144	19821.66	207.6918	43.35161	0.4139585	27297.04	13.71457
PJ145	18352.82	197.1125	43.88676	0.4278259	27511.09	14.03992
PJ146	19104.38	208.6429	45.23391	0.4080783	27316.61	15.01973
PJ147	19100.51	214.8916	43.27847	0.4143918	26689.85	14.02572
PJ147A	19866.73	216.4336	45.78644	0.4292707	28785.31	14.9166
PJ148	21020	226.3549	44.70272	0.420212	27972.39	14.67155
PJ149	19938.88	212.7645	44.02173	0.3850181	26138.52	13.23792
PJ150	20731.92	223.1234	44.75423	0.418811	27175.32	14.69461

Sample ID	U	YB	BA	CE	CO	CR
PJ082	0.7321091	2.875382	352.1606	96.30964	37.46238	7.885256
PJ082A	0.8992896	2.979448	246.8863	88.92897	34.47116	3.087432
PJ083	0.8523895	3.034034	282.49	86.44901	34.69474	2.334691
PJ084	1.004947	3.193758	305.9186	89.74551	34.53546	3.155298
PJ085	1.025567	2.953487	263.3302	87.61508	33.10706	2.29025
PJ086	1.003501	3.029161	276.5295	87.40142	34.32319	2.50158
PJ087	0.8797916	3.210032	287.9842	93.08698	37.1317	5.193551
PJ087A	0.9792708	3.254768	251.993	79.17014	34.97087	2.625554
PJ088	0.6866328	2.763538	264.8224	103.9783	39.49444	3.757044
PJ089	0.8597047	3.194196	237.8421	89.87962	35.36817	2.039633
PJ090	0.8840677	2.875762	269.4346	89.21889	35.41377	1.885044
PJ121	0.8855218	3.747991	270.6086	98.90072	33.49967	2.497016
PJ122	0.9142615	4.108006	376.2912	95.96358	34.06393	2.520068
PJ123	1.375708	3.605375	307.7682	106.1824	35.62995	1.437771
PJ124	0.8183987	3.54118	328.9694	111.7559	36.58477	2.339088
PJ125	1.046314	3.394857	319.7885	110.343	37.83991	2.943289
PJ126	1.017831	3.509324	307.3376	120.2831	39.71038	3.246797
PJ127	1.038924	3.692032	310.5431	91.33161	29.14466	2.128447
PJ127A	1.279806	3.617803	336.4164	102.3448	32.7346	3.041389
PJ128	1.135052	3.738769	371.5432	125.8466	40.23621	3.465261
PJ129	1.499784	3.984922	345.6363	111.0963	36.97128	3.032114
PJ130	1.517956	4.189378	337.9748	108.6769	37.16586	3.136994
PJ131	0.8301711	3.553149	371.195	108.9807	35.56734	2.944836
PJ132	1.290283	3.462324	344.7619	116.1833	37.92453	2.172391
PJ133	0.7381026	3.377303	269.1837	88.66432	28.34469	1.829408
PJ134	0.8394727	3.034029	352.2357	93.59855	32.50562	2.366458
PJ135	1.212155	3.688859	311.4515	98.7209	31.94546	2.366787
PJ135A	0.9614336	3.351674	277.9521	94.51527	30.44121	2.266249
PJ136	0.9655432	3.219973	294.8982	98.47641	32.64822	1.574452
PJ137	1.032673	3.29124	348.4068	106.0963	32.98378	2.607098
PJ138	1.147774	3.460719	411.8707	115.3638	38.30779	2.175484
PJ139	1.19955	3.18661	317.0324	102.4332	35.78506	2.320048
PJ140	0.9698207	3.823102	348.8407	113.5317	34.98501	2.720035
PJ141	1.086329	3.305355	296.9807	106.1409	33.38009	2.705437
PJ142	1.18348	3.446203	280.6524	104.7321	35.56169	2.380929
PJ142A	1.059965	3.567731	338.2711	104.3194	32.16487	2.979588
PJ143	1.07016	3.616946	350.163	114.5505	34.47035	3.057817
PJ144	1.219055	3.483392	306.3669	96.9516	32.74736	2.034426
PJ145	1.179117	3.15755	277.329	106.0369	35.05198	2.770902
PJ146	1.025684	3.212264	296.3287	108.6938	37.47618	2.991846
PJ147	1.106921	3.079958	314.4567	91.78497	31.27168	1.514215
PJ147A	1.035304	3.441092	244.8481	95.55564	32.21537	3.255133
PJ148	1.058454	3.607534	295.3188	102.2549	33.19218	4.209133
PJ149	0.8435208	3.436524	227.1591	94.4938	28.69676	1.848256
PJ150	0.8715923	3.496426	246.2086	95.47581	32.11164	2.161154

Sample ID	EU	FE	HF	ND	RB	SC
PJ082	4.411187	101085	10.20284	55.67623	40.39067	15.15287
PJ082A	4.100994	93170.31	9.865206	43.1925	41.09492	14.04147
PJ083	4.068747	89417.74	9.17618	44.567	41.39154	13.66453
PJ084	4.159359	92472.6	9.675934	45.18781	39.39655	14.0577
PJ085	4.102709	91565.17	9.195019	44.41341	43.19376	13.6646
PJ086	4.205273	90999.76	9.705897	43.56393	46.16043	13.8303
PJ087	4.345838	91868.48	9.815265	46.54012	43.11627	14.80343
PJ087A	3.951962	87585.55	8.881138	40.0836	34.48122	13.35755
PJ088	4.58115	104996.3	10.65964	57.57285	46.54438	15.9031
PJ089	4.125552	94794.88	9.746565	43.23426	37.8026	14.17589
PJ090	4.242902	94565.04	9.424513	44.91197	38.37645	14.31991
PJ121	4.763742	97389.72	11.05211	50.22736	41.00497	14.37329
PJ122	5.058486	99986.03	11.67341	61.06322	26.45251	14.84263
PJ123	4.898512	94007.45	11.43723	52.91797	38.01207	14.67705
PJ124	5.553305	102712.5	12.10022	60.576	47.70156	15.09507
PJ125	5.144618	100009.2	12.21764	50.86993	51.21816	15.03175
PJ126	5.346776	106652.6	13.25968	54.27797	63.03625	16.19737
PJ127	4.276951	89232.05	10.0784	44.20967	43.64625	12.71108
PJ127A	4.905918	95595.54	11.7892	54.34954	51.24763	14.27785
PJ128	5.654476	109843	13.72745	63.19104	59.29035	16.80075
PJ129	5.129588	97674.16	12.10837	56.41333	56.53056	15.34284
PJ130	5.076052	98692.92	11.89704	54.52946	48.30863	15.09876
PJ131	5.433002	107778.7	12.29574	60.91522	35.299	16.11784
PJ132	5.170368	103533.3	12.43332	58.92274	49.10997	15.82525
PJ133	4.709099	85752.38	10.08642	47.44442	26.68159	12.91398
PJ134	4.807634	93518.02	9.609975	50.87011	30.01369	13.96797
PJ135	5.099886	94604.24	11.25895	55.06672	44.369	14.31098
PJ135A	4.72504	91919.02	10.66475	49.60152	43.40255	13.7268
PJ136	4.581142	91007.02	10.47154	49.80609	39.61334	13.63767
PJ137	5.109625	105685	11.9361	54.8045	46.25368	15.02755
PJ138	5.283592	110019.9	12.85418	60.40204	54.8296	16.12008
PJ139	4.760349	92865.13	11.10845	49.29718	42.95347	14.16765
PJ140	5.897103	105665.8	12.55457	63.69432	50.82826	15.5833
PJ141	4.838075	94463.89	11.65102	52.43936	40.25995	14.45371
PJ142	4.839565	94672.39	11.23852	53.14968	41.15136	14.51995
PJ142A	5.290573	95881.93	11.48059	55.74044	45.45015	14.24043
PJ143	5.350273	105023.6	12.56605	58.76413	41.91144	15.7895
PJ144	4.554776	91734.56	10.7092	49.01288	41.59827	13.4709
PJ145	4.788359	92933.96	12.10522	55.04622	50.68682	14.09061
PJ146	4.758414	103661.4	12.15341	59.39255	57.15079	14.81145
PJ147	4.207998	83337.26	10.27274	49.41504	43.06627	12.79657
PJ147A	4.431223	88354.78	10.48357	52.66306	38.04028	13.40668
PJ148	4.65112	92154.52	11.08349	49.92422	41.85868	14.12197
PJ149	4.386492	84569.76	10.33011	46.04824	41.98318	12.90815
PJ150	4.492709	88814.28	10.62208	46.88955	31.93903	13.42213

Sample ID	SR	TA	TB	TH	ZN	ZR
PJ082	689.688	3.118952	1.94226	4.140827	171.3212	338.1967
PJ082A	687.106	2.860832	1.918756	4.065444	167.6783	289.9351
PJ083	672.9158	2.831524	1.674461	3.776485	171.8522	282.5847
PJ084	735.9168	2.995622	1.720578	4.017715	177.2799	308.1455
PJ085	749.3313	2.891352	1.671511	3.888546	161.6936	261.6291
PJ086	710.1086	2.976958	1.602547	3.860816	170.5805	270.6697
PJ087	709.6741	2.94413	1.649676	3.935031	201.452	265.12
PJ087A	604.2771	2.829702	1.52116	3.608798	162.6864	242.9931
PJ088	807.5617	3.133382	2.21309	4.508087	206.0729	343.4503
PJ089	709.5696	2.892962	1.950043	3.83858	173.1672	366.7541
PJ090	757.3859	2.919303	1.887033	3.850053	178.1158	347.1128
PJ121	711.3997	3.267442	1.847015	4.309876	192.0369	286.803
PJ122	580.9619	3.432978	2.045113	4.707655	208.4891	262.2788
PJ123	677.575	3.359388	1.857378	4.56999	208.1025	308.5157
PJ124	744.8937	3.535417	2.404144	4.85963	198.6671	288.4327
PJ125	799.1101	3.731266	2.308465	5.083469	221.3044	279.0087
PJ126	937.924	4.068764	2.572441	5.531702	247.732	318.7638
PJ127	560.6274	2.818434	1.574751	3.974339	166.2875	253.7475
PJ127A	738.2283	3.477974	1.895579	4.867022	186.3684	314.8177
PJ128	921.4312	4.182253	2.677063	5.752234	241.1321	318.9949
PJ129	817.9897	3.923063	2.089823	5.076898	208.3444	373.1909
PJ130	810.0385	3.843524	2.091368	5.045773	198.178	347.5218
PJ131	763.1985	4.078207	2.201805	5.123773	209.5492	349.9507
PJ132	833.8903	3.89687	2.045101	5.206318	216.8203	387.8296
PJ133	614.4006	2.906354	1.678466	4.000632	161.9359	314.1207
PJ134	637.7806	3.041195	1.790425	3.663849	181.4578	318.8604
PJ135	656.7077	3.507415	2.066314	4.70954	185.2022	349.1894
PJ135A	591.6719	3.075157	1.775808	4.307975	177.3844	323.3535
PJ136	694.1618	3.22007	1.846749	4.290165	185.0941	301.9459
PJ137	725.4721	3.459033	1.928034	4.797534	183.0027	372.2328
PJ138	778.189	3.685926	2.184472	5.153151	218.1607	422.0977
PJ139	699.1853	3.347195	1.89469	4.510113	169.2659	348.0428
PJ140	772.4261	3.621115	2.372698	5.088153	200.1936	388.3006
PJ141	728.8725	3.37256	1.943103	4.5969	188.8418	406.0256
PJ142	682.7491	3.339104	1.939852	4.475003	182.1768	325.943
PJ142A	747.5931	3.380032	2.01311	4.626992	181.5904	369.4409
PJ143	856.6198	3.777182	2.333928	5.10626	203.0878	427.5017
PJ144	709.3121	3.235043	1.823522	4.257861	172.3624	357.559
PJ145	656.2963	3.432589	1.912205	4.955027	169.8594	369.5132
PJ146	705.3847	3.536377	2.052712	4.892393	191.3826	393.4021
PJ147	634.8204	3.095261	1.859618	4.170311	193.8753	372.8733
PJ147A	661.8589	3.058413	2.115752	4.17891	181.4154	367.4465
PJ148	721.7163	3.263614	2.175238	4.608328	185.2543	330.7762
PJ149	671.0117	3.004881	2.067111	4.182104	159.2235	295.043
PJ150	697.329	3.160273	2.099188	4.187464	174.1013	264.0578

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